ECONOMIC ANALYSIS OF ALTERNATIVE IRRIGATION TECHNOLOGIES:

TEXAS LOWER RIO GRANDE VALLEY

A Thesis

by

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Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2012

Major Subject: Agricultural Economics

ABSTRACT

The focus of this study is the economic feasibility of drip irrigation adoption using capital budgeting and quadratic programming techniques. The capital budgeting techniques used in the study are net present value (NPV) and returns above specified costs (RASC). Modified crop enterprise budgets incorporating drip irrigation are developed based on data from Texas AgriLife Extension Service crop enterprise budgets and published literature focusing on costs and returns of drip irrigation. The quadratic programming technique considers risk and incorporates the modified crop enterprise budgets to estimate a cropping pattern that maximizes the net income above specified costs for the region.

The RASC per acre for drip-irrigated crops ranged from $56.34 to $1,909.03, while the RASC per acre for flood-irrigated crops ranged from $142.51 to $1,488.12. Flood-irrigated onions, cotton, and sugarcane had higher RASCs per acre, while the RASCs were greater for drip-irrigated grapefruit and oranges. Evaluating the NPV of the crops resulted in similar results; only grapefruit and oranges were economically-feasible drip-irrigated crops.

The baseline results identified levels of drip irrigation adoption ranging from 52,000 acres to 64,497 acres as levels of risk were varied. The level of water available at the reservoir suggested minimal impacts on the level of drip-irrigation adoption, but serious implications for the agriculture economy. Several sensitivity scenarios concentrated on the implications of yield response and water savings that result from the adoption of drip irrigation. The greatest amounts of drip-irrigated crops were present when the yield responses were 130% of the flood-irrigated crops with a 20% water savings. As the amount of water available was reduced, the amount of drip-irrigated crops ranged from 46,111 acres to 59,724 acres.

Drip irrigation appears to be an economically-viable alternative in the LRGV due to the presence of drip-irrigated crops in the entire myriad of scenarios investigated in this research. If producers are only concerned with the bottom line as provided by the RASC analysis and no other variables such as water availability, risk, and crop rotations affecting the decision making process, only drip-irrigated grapefruit and oranges are economically competitive with conventional irrigation systems.

ACKNOWLEDGMENTS

There are many people who have provided support, mentorship, and encouragement throughout the research and writing stages of this thesis. Two men who have been instrumental and involved throughout this process were my committee co-chairs, Dr. Ed Rister and Dr. Ron Lacewell. Dr. Rister played an instrumental role in my decision to pursue graduate studies; moreover, without his support and employment as a teaching assistant, I would not have been financially able to complete this program while supporting a wife simultaneously. Words cannot describe the gratitude and respect I have for Dr. Rister for the insight and advice he has given me not only with this thesis and graduate studies, but life in general. I would also like to thank Dr. Lacewell for his guidance and support in the development and preparation of this thesis. I am immeasurably grateful for the mentorship he has provided. Acknowledgement and gratitude are due to Dr. Gilley and Dr. Robinson, who have provided invaluable knowledge throughout the process of developing this thesis. I must also thank Allen Sturdivant for his help during trips to the Lower Rio Grande Valley.

Without the support and guidance received from Michele Zinn, Kari Moore, and Dr. Shelley Peacock, my graduate school experience would have been much more stressful. Thanks also go to my colleagues, Dr. Naveen Adusumilli, Edgar Alarcon, Ann Conrad, Lindsi Dutton, Jordan Glasener, and Dr. Andrew Leidner for their friendship, insight, and support along the way. Finally, I would like to thank my wife, Ashly Wilbourn, for her patience love, and support as I work towards the accomplishment of my goals.

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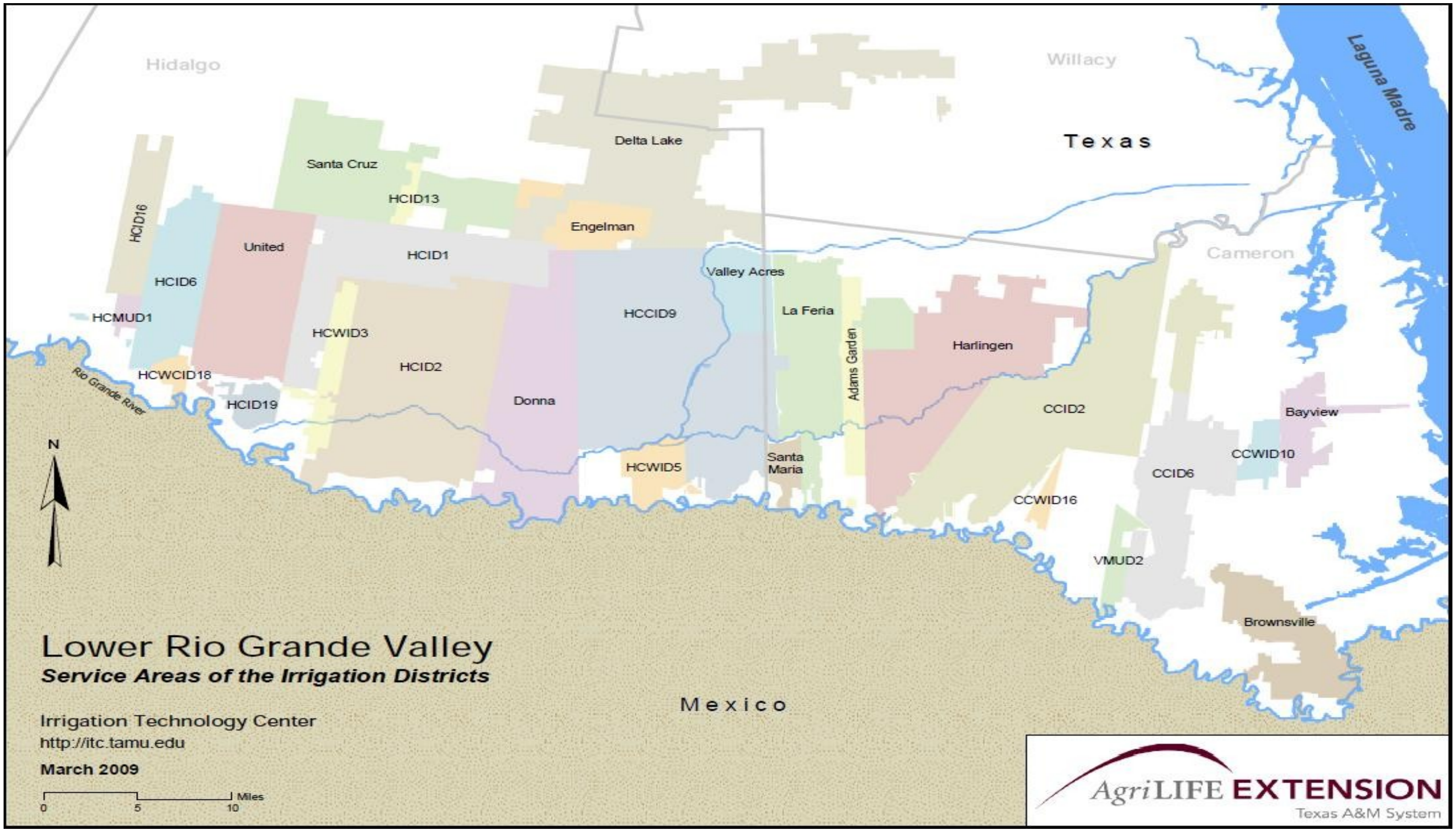
INTRODUCTION

The Rio Grande stretches over 1,800 miles, with its headwaters located in southern Colorado (Lacewell et al. 2010). The river is fed by melting snow from the Rocky Mountains and flows through Colorado, New Mexico, and Texas, eventually reaching the Gulf of Mexico at the international border between the U.S./Texas and Mexico. Due to reduced flow around Fort Quitman, Texas, there are actually two sections within the Rio Grande. The first section extends from the headwaters in Colorado to Fort Quitman, Texas, while the second part flows from below Fort Quitman, Texas to the Gulf of Mexico. The second part of the Rio Grande is fed mainly by inflows from the Rio Conchos and the Pecos River (HARC 2008). Two reservoirs, Falcon and Amistad, were built along the lower portion of the Rio Grande in 1954 and 1969, respectively, to create a reliable water supply for downstream users (HARC 2008). The allocation of water from the reservoirs is governed by the International Boundary and Water Commission (IBWC) according to the 1944 International Water Treaty (Stubbs et al. 2003).

The population in the Rio Grande Valley is expected to increase by 142% between 2010 and 2060, with net water demand increasing in the region by an estimated 13% (Texas Water Development Board 2006). The Rio Grande is the major source of water for the region's agricultural, industrial, and municipal users. As the demand for water increases due to the increased population and associated business and industry, water conservation will continue to be viewed as one of the least cost solutions. One highly-advocated strategy of conservation directed to agricultural producers relates to adopting more efficient irrigation technologies (Ørum et al. 2010).

For this study, the Texas Lower Rio Grande Valley area is defined as five counties -- Cameron, Willacy, Hidalgo, Starr, and Zapata. Cameron, Willacy, and Hidalgo comprise the vast majority of cropped acres in the region. There are a total of 29 irrigation districts throughout these counties which are shown in Figure 1 (Leigh, Barroso, and Fipps 2009). The agriculture in the area is diverse, ranging from vegetables to sugarcane. Table 1 includes identification of the primary crops planted in each of the five counties and the number of irrigated and dryland acres that were harvested in 2007 (USDA-NASS 2007). Starr and Zapata counties have a limited number of irrigated cropland acres due to only one irrigation district being located in Zapata County.



Source: Leigh, Barroso, and Fipps (2009)

Figure 1. Map of irrigation districts in the Texas Lower Rio Grande Valley, 2009

Table 1. Primary Crops Planted in Each County of the Texas Lower Rio Grande Valley and Their Respective Acreages, 2007

County	Cameron		Hidalgo		Willacy		Starr		Zapata		Total	
Crop	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Dryland
Sorghum for Grain	51,292	63,249	57,820	111,813	8,911	96,166	1,666	37,570	0	0	119,689	308,798
Forage	3,673	2,801	5,409	8,161	822	2,299	2,344	15,611	416	1,653	12,664	30,525
Corn for Grain	12,910	3,204	15,564	5,810	184	1,432	1,123	-[a]	0	0	29,781	10,446
Vegetables	4,390	931	19,339	10,174	516	28	506	250	-[a]	-[a]	24,751	11,383
Cotton	9,711	16,449	14,860	3,357	3,301	41,197	13,243	3,663	0	0	41,115	64,666
Sugarcane	8,072	949	24,394	4,411	-[a]	-[a]	0	0	0	0	32,466	5,360
Land in Orchards	2,183	858	20,600	4,303	52	91	74	13	0	0	22,909	5,265
Total	92,231	88,441	157,986	148,029	13,786	141,213	18,956	57,107	416	1,653	283,375	436,443

Source: USDA-NASS (2007)

[a] The data collected for this item was withheld to avoid disclosing details for individual farms.

Objective

The purpose of this research is to evaluate the potential economic feasibility of drip irrigation as compared to traditional irrigation systems in the Texas Lower Rio Grande Valley (LRGV) for alternative crops such as citrus, onions, cotton, and sugarcane. The criteria to determine the economic feasibility of drip irrigation in this study are based upon the returns above specified costs (RASC) and net present value (NPV) compared to conventional irrigations systems. In addition to the evaluation of the economic feasibility, the resource feasibility is also evaluated using a regional analysis, which takes into consideration the amount of the resource, water, which is available to determine if it is feasible to adopt drip irrigation according to the parameters of the crop enterprise budgets. The results of this study will provide insight to area producers of the economic implications associated with drip irrigation compared to their current method of irrigation. A typical irrigation system in the region is flood or furrow that uses gravity to distribute water across a field (Enciso and Périès 2007).

The null hypothesis of this research is: “The adoption of drip irrigation in the Lower Rio Grande Valley is not economically feasible.” The alternative is: “The adoption of drip irrigation in the Lower Rio Grande Valley is economically feasible.” The proposed research will address these hypotheses based on budgeting analysis with a comparison to conventional irrigations system and a modified version of a regional optimizing model developed by Robinson, Michelsen, and Gollehon (2010). The optimizing model will be modified to include drip irrigation and applied to test economic implications of new irrigation technologies. With this set of hypotheses, the options are (a) the null hypothesis is rejected and the alternative hypothesis is accepted or (b) fail to reject the null hypothesis. These hypotheses will be evaluated subjectively rather than statistically by comparing the economics of conventional methods of irrigation and the proposed method of drip irrigation for several scenarios of total availability of water for the region, yield impact, and water application rate.

When evaluating efficiency, there are two types: technical efficiency and economic efficiency. Heady (1952) defines technical efficiency as "the measure of the magnitude of the physical ratio of the product output to the factor input." As this value increases, the technology has a greater technical efficiency. Economic efficiency is the measure at which resources are used in a way to maximize an objective such as profit (Heady 1952). Technical and economic efficiencies are similar in that the goal is to operate at an optimal level in which a specific value is maximized (or minimized). However, they are different in that economic efficiency will maximize an objective such as profit (based on monetary values of output and input), while technical efficiency will maximize the level of physical output given a specified level of physical input. This research is directed to economic efficiency.

Structure of Thesis

This thesis is presented in a section format. The sections that follow include sections discussing the relevant prior published literature, theory of production economics, methodology, results, limitations, and conclusions.

LITERATURE REVIEW

Irrigation is an essential practice for production of several crops in the Texas Lower Rio Grande Valley (LRGV) (especially vegetable, citrus, and sugarcane), enhancing yield and quality and mitigating variability for those crops compared to dryland practices, particularly related to cotton, sorghum, corn, and pasture. The LRGV receives between 22 and 26 inches of rainfall per year, while citrus, one of the high-value crops in the region, requires between 35 to 48 inches of water per year to achieve a reasonable level of production and yield (Enciso et al. 2008). Other crops grown within the region such as vegetables and sugarcane also require substantial, timely irrigation to be economically viable.

Given that irrigation is essential for the sustainability of high-value crops supporting the agricultural economy in the LRGV, there are potential risks associated with limited water supplies in times of drought and/or issues related to the international border as well as the potential effects of global climate change. Agricultural producers are concerned about saving water, but also are driven by economics. Some literature (Jury and Vaux 2005) suggests/encourages adoption of the most technically-efficient irrigation system, when in reality agriculture needs a balanced analysis of the trade-off between technical and economic efficiency along with awareness of incentives and barriers for producers to adopt such technology.

Water Conservation

The majority of recent work related to water conservation in the LRGV is associated with several Rio Grande Basin Initiative projects. The Rio Grande Basin Initiative is a federally-funded project that was coordinated through the Texas Water Resources Institute during 2002-2012. The project focuses on increasing available water, meeting water demands, and creating new sources of water (Texas Water Resources Institute 2011). Many of the projects concentrate on water conservation through the rehabilitation of irrigation district (ID) water delivery systems (Rister et al. 2008). The types of projects that have been evaluated include ID canal lining, pipeline installation, and water meter and telemetry installation. Indicated in Table 2 are the average annualized costs associated with conservation of an acre-foot of water, and the amount of acre-feet that are saved annually through installation and implementation of such ID rehabilitation projects.

Table 2. Annual Costs of Saving Water via Rehabilitation Projects in the Texas Lower Rio Grande Valley, 2008

Rehabilitation Project	Annual ac-ft saved	Average \$/ac-ft
Canal Lining	34,700	\$35
Pipeline	19,260	\$56
Meters and Telemetry	4,287	\$83
Total	52,247	\$45

Source: Rister et al. (2008)

Water Rights

The Texas Lower Rio Grande Valley area has 29 IDs (Stubbs et al. 2003) that distribute water from the Rio Grande to agricultural producers and municipalities. The IDs request water from the Watermaster, which results in the release of water from Falcon Reservoir (Wolfe et al. 2007a). Once the water reaches the IDs pumping stations, it is diverted to ID canals and delivered to the farmer (Wolfe et al. 2007b). The allocation of water that is diverted from the Rio Grande is defined by the U.S. – Mexico Treaty for Utilization of the Waters of the Colorado and Tijuana Rivers, more commonly known as the 1944 International Water Treaty. This treaty states that Mexico must deliver an average of 350,000 acre-feet of water annually over each five-year cycle (Stubbs et al. 2003). In the mid-1990s, Mexico did not meet this obligation, leading to a shortage of irrigation water for agricultural producers in the U.S. (Robinson 2002). The damages caused by these water shortages in the LRGV were estimated by Robinson, Michelsen, and Gollehon (2010). The results indicate a total amount of damages between 1998 and 2004 of $16.33 million. This value includes the opportunity cost of the water and the interest accrued from 1998 until payback of the water deficit in 2004.

Producers cannot be expected to adopt expensive, water-saving irrigation technology if they have no incentive. An institutional complexity related to adoption of water-technologies in LRGV IDs relates to water rights. Based on the adjudication of water rights in 1969 from the lawsuit, State of Texas v. Hidalgo County Water Control and Improvement District No.18, the water rights were assigned to the IDs (Stubbs et al. 2003). With the ownership of water rights associated with the IDs rather than individual producers, there are no direct incentives for the producers to save water. That is, any and all water saved is credited to an ID as a whole rather than to individual producers.

Another factor for the LRGV relates to the existence of the 29 IDs and the pricing structure for the irrigation water. There are cases where water is charged on a per unit basis (per acre-inch for example) while others charge a fee per acre per irrigation. Such a water delivery rate structure has major implications for the type of irrigation system the producers will adopt since drip irrigation applies water frequently in small amounts.[1]

Irrigation Systems and Characteristics

A variety of literature helps to better understand and comprehend the components of this research. This literature review includes a background on the LRGV area and the types of irrigation currently in use, the advantages and disadvantages of drip irrigation technology, and a review of past studies related to the economic feasibility of drip irrigation.

Texas AgriLife Extension Service recently completed a survey of LRGV ID managers relative to the types of irrigation practices that are currently in place. Enciso and Périès (2007) found that only a small portion of area producers are currently using drip irrigation. They determined that only about 1.6% of the irrigated acres in the LRGV land utilize drip irrigation, with the main technology (95%) in place being flood irrigation.

[1] Thus far, LRGV ID water delivery rates are structured such that no economic savings accrue to producers using drip irrigation. IDs incur higher per unit costs for delivering water for such technologies, resulting in no essential benefit for the producer in the form of lower water delivery cost on a per acre basis (Hinojosa 2011).

An issue of interest relates to the actual water use for a so-called more efficient irrigation system compared to other systems. Results published to date suggest that water use associated with different alternatives is highly variable. The adoption of a more efficient irrigation technology can result in water savings (Huffaker and Whittlesley 2000; Peterson and Ding 2005). However, there are also studies in which as the irrigation technology efficiency increases, the amount of water that is used increases as well (Ward and Pulido-Velazquez 2008; Mullen 2011). This can be explained by economic theory in that a system such as drip reduces marginal costs, providing incentive for greater use. Gilley and Supalla (1983) stated that the amount of water applied not only depended on the irrigation technology, but also the irrigation management practices used by the producer. Another factor relates to the implications that when water is delivered by a canal system to drip irrigation, the canal must always be charged to meet the drip system requirement. A drip system applies small amount of water often (i.e., frequently), while flood irrigation is only needed every one or two weeks. One solution is an on-farm reservoir where water used to irrigate with drip irrigation is obtained infrequently and stored until used (Heller 2011). One cannot say with certainty that adoption of a more efficient irrigation system will lead to reduced water use.

As with any type of investment in technology, there are advantages and disadvantages to adopting drip irrigation. A few of the advantages of drip irrigation include potential of less water applied to crops, a more uniform application of water, and improved fertilizer management (Lamm 2002). Other potential benefits may include increased yield, uniformity of product, and improved quality of product. With drip irrigation, less water is lost due to evaporation, runoff, and deep percolation, compared with flood irrigation. However, this also depends on management practices (amount of water applied per irrigation) and soil type (Gilley and Supalla 1983). Drip irrigation also permits the producer to apply fertilizer through the drip lines rather than via a separate machinery field operation. Lamm (2002) presents some disadvantages of drip irrigation, including a smaller wetting pattern, crop rotation issues, and the large requisite capital investment.

The economic literature regarding the adoption of drip irrigation has primarily focused on areas that irrigate with groundwater, as opposed to irrigating from surface water. Cuykendall and White (1998) studied the economic feasibility of drip irrigation in apple orchards in New York in which the costs and production data were assimilated to determine the net present value of net revenue over a seven-year time period at a ten percent discount rate. The results of this study showed that the NPV was $1,558 per acre for a tape system and $1,412 per acre for pressure-compensating tubing. Since the NPV is strongly positive, the investment in drip irrigation for apple orchards is economically feasible. There has also been work published on the economics of drip irrigation of olives (Cetin, Yazgan, and Tipi 2004). The authors followed the same basic procedures as the literature on apples in determining the net present value of drip irrigation used for olives. The results of this work show that investment in drip irrigation in Turkey is also economically feasible. The NPV (benefit) of the installation of drip irrigation was $3,464 per hectare, with an initial investment of $2,244 per hectare over a seven-year planning horizon.

Work has also been published that compares the costs and receipts of flood irrigation and drip irrigation in the LRGV for Rio Red Grapefruit (Young et al. 2009). This work analyzed a project site created by the Agricultural Water Conservation Demonstration Initiative which demonstrates new technologies that maximize water use efficiency. The authors found that there was not a significant difference in the costs or returns that were realized for the project site between flood and drip irrigation.

THEORY

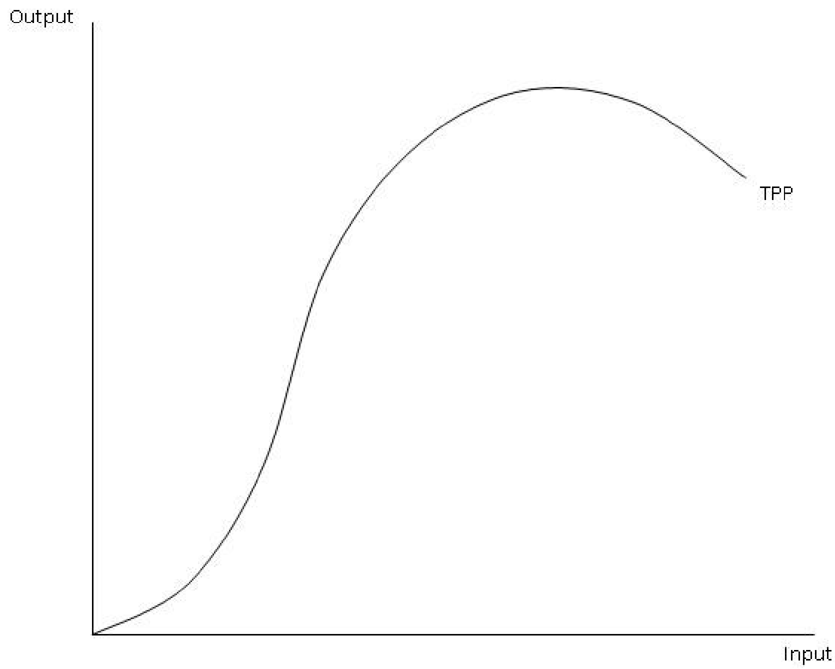
The overall objective of this research is to conduct an economic analysis of drip irrigation technology compared to traditional flood or gravity flow irrigation. Because this is an economic-based project working with water, certainly there is a basis in economic theory underlying the analysis. This section is an overview of basic theoretical concepts related to the analysis. The discussion is based on production economics, beginning with a production function and its relationship to costs and returns.

Production Function

The field of production economics involves the decision-making strategies of producers to enable them to maximize an objective function, such as profit, by choosing how much input to use, or alternatively how much output to produce. A production function for an output or crop provides the basis for estimating how much of a selected input to use. The production function describes the relationship between inputs and outputs (Debertin 1986).

Total Physical Product, Average Physical Product, Marginal Physical Product

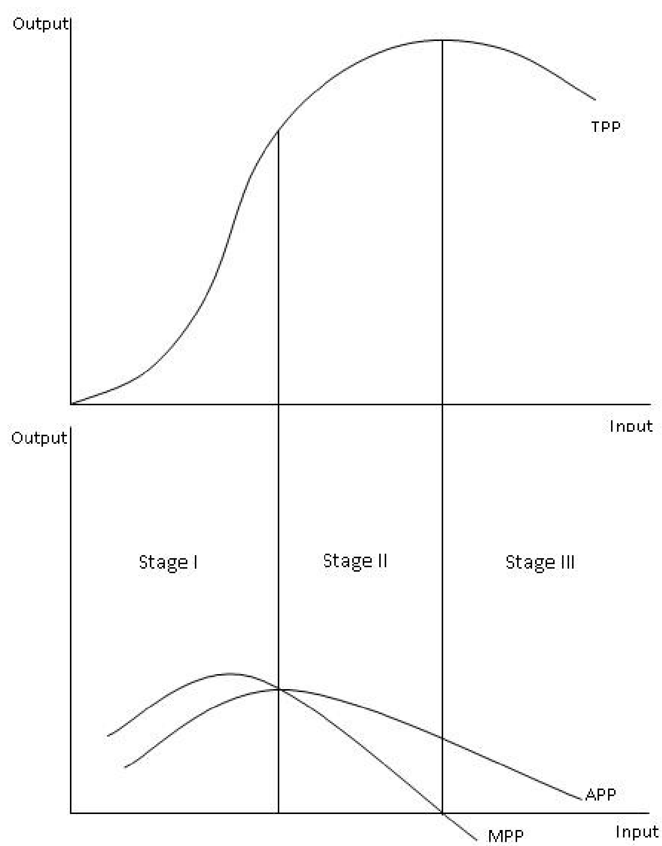
The output of a production function is referred to as Total Physical Product (TPP). Figure 2 is a graphical representation of the relationship of output to input or a traditional production function.



Source: Kay and Edwards (1999)
Figure 2. A traditional production function

Several relationships can be established between the total physical product and the amount of inputs that are applied to a crop. The average physical product (APP) produced by an input is estimated by dividing the total physical product (TPP) by the input level at each point on the production function or schedule. This is APP = TPP/input. This value is the average amount of output that is produced per unit of input at each level of output (Kay and Edwards 1999). The APP can be found graphically by determining the slope of a line that is drawn from the origin to a point on the graph (Debertin 1986). When this line from the origin is tangent to the TPP, the APP is at a maximum.

The marginal physical product (MPP) represents the amount of output attributable to the last unit of input. This is the concept of the margin for decision makers. The MPP is calculated by dividing the change in output by the change in input, or MPP = ΔTPP/ΔInput. This is the first derivative of the production function (TPP). The slope of the TPP at each point is the MPP of that point. The MPP and APP intersect at the APP at the maximum point of the APP. The MPP is valuable to a decision maker for it indicates how much additional output is produced if one more unit of input is applied. Illustrations of MPP, APP, and TPP are presented in Figure 3.



Source: Debertin (1986)

Figure 3. Stages of production derived from the traditional production function

Stages of Production

Production functions generally reflect part or all of the shape shown in Figure 2. The amount of input that is applied to the crop is represented on the x-axis (horizontal axis), while the output that is produced for the corresponding number of inputs is represented on the y-axis (vertical axis). As the initial amounts of inputs are applied, the amount of output increases at an increasing rate, resulting in increasing marginal returns (Heady 1952). The output then increases at a decreasing rate, and ultimately increases at a negative rate leading to negative marginal returns (Heady 1952). As a result of the shape of a traditional production function, there are three stages of production. The first stage of production (Stage I) occurs from the origin of the function (no inputs) to the point at which the marginal physical product (MPP) equals the average physical product (APP). At this point the slope of a line from the origin to the TPP is equal to the value of the APP.

Stage II occurs from the end of Stage I to the maximum level of output (TPP), or where the rate of change of the output is zero and additional inputs actually reduce output. Stage III occurs when the rate of change in the amount of output that is produced becomes negative as more inputs are added. Illustrations of the three stages of production relative to TPP and associated MPP and APP are shown in Figure 3. The rate at which the output is produced by adding more units of inputs decreases as the number of inputs increases due to the law of diminishing marginal returns. The law of diminishing marginal returns states that the marginal physical product will decline as additional inputs are added to a fixed set of inputs (Kay and Edwards 1999).

There are stages of production that are irrational, such as Stages I and III. It is irrational for a producer to operate in Stage I because output is increasing at an increasing rate for each additional unit of input. Since a greater amount of outputs can always be realized with each added unit of input, it is irrational to stop using inputs when the output will increase at an increasing rate leading to greater profits (Heady 1952). Stage III of production is also irrational because the output declines as additional units of input are applied (Debertin 1986). Since the amount of output declines when more inputs are applied, it is more rational to use fewer inputs and operate in Stage II. Stage II is known as the rational stage of production. The economic issue is estimating where in Stage II to produce to maximize profit.

Economic Principles

By applying input price and output price, the production function (TPP) is converted to represent dollar relationships. For example, by multiplying TPP by the market price, the Total Value of the Product, or TVP, is estimated which transforms the output into dollar terms (Debertin 1986). The TVP is essentially the revenue that is received at a specific level of input. By multiplying the MPP by the market price of the output, the amount of additional income that will be generated by using an additional unit of input is estimated. This value is known as Marginal Value Product (MVP) or Value of the Marginal Product (VMP). There are costs associated with the inputs that are used to produce the output. These costs are known as total factor costs (TFC). As the number of inputs increases, the total factor costs increase at a constant rate with the slope of the TFC being the market price of the inputs that are used (Debertin 1986). The TFC is calculated by multiplying the market price of the inputs by the number of inputs that are used. The first derivative of the TFC is the marginal factor cost (MFC) and is a horizontal line, or the price per unit for the input. This value is the added costs that are incurred as one additional unit of input is used.

Maximizing Net Returns

From the basic production function, the profit-maximizing position can be addressed relative to output or input. The solution is the same from either perspective. Basically, economic studies are designed to estimate where net returns will be maximized. It is typically assumed that a producer will respond to those incentives that improve their net economic position. It is appropriate to begin with the profit-maximizing condition.

Input

For discussion purposes, the theoretical underpinning of economic theory with regards to the optimal input side is initially presented. For profits to be maximized, a producer will operate within Stage II where the marginal value product (MVP) equals the marginal factor cost (MFC), or where the added economic return is the same as the cost for the last unit of input. This can be shown with economic theory by stating the formula for profit. Profit is total revenue minus total costs. The total revenue received can be restated as the total value of the product (TVP), while the costs associated with the product are known as the total factor costs (TFC). In technical terms, profit equals TVP minus TFC. To represent this in terms of calculus, the maximum of an equation is found by setting the first derivative of a function to zero. After taking the first derivative of the profit function, the result is ∂profit=MVP-MFC. When this derivative is set equal to zero (the maximum profit level), the mathematical equation that results is 0=MVP-MFC (Debertin 1986). This equation can be rewritten to state that MVP=MFC at the maximum level of profit. That is, variable inputs should be added to the point where the last dollar of input generates a dollar of revenue.

By establishing the condition where a producer maximizes profit, the discussion can be expanded to explore the implication of new technology and price changes. Applying profit-maximizing conditions to drip irrigation, for example, it is generally considered that switching to a more efficient irrigation system will result in water conservation and/or a yield (TPP) increase per unit of input, or water applied. If the MVP shifts as a result of an increase in yield per unit of water applied, or the MFC of the irrigation water decreases as a result of the new irrigation technology, producers will have an economic incentive to use more water. A change (increase) in the MVP from MVP_1 to MVP_2 due to an increase in yield as shown in Figure 4 leads to increased optimal water usage from Q_1 to Q_2. The effects of a reduced MFC of irrigation water from MFC_1 to MFC_2 can be shown in Figure 5, in which the optimal amount of water used for irrigation increases from Q_1 to Q_2.

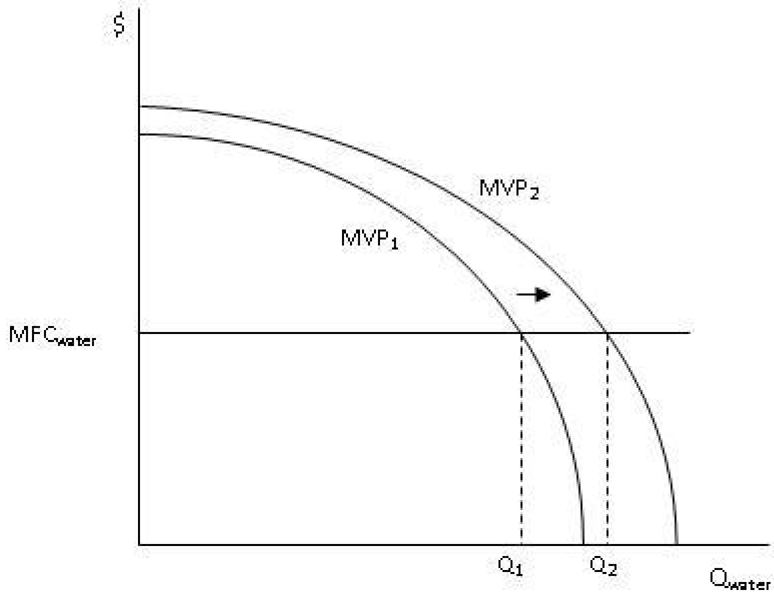


Figure 4. Implications of an increase in marginal value product (MVP) due to the adoption of new technology

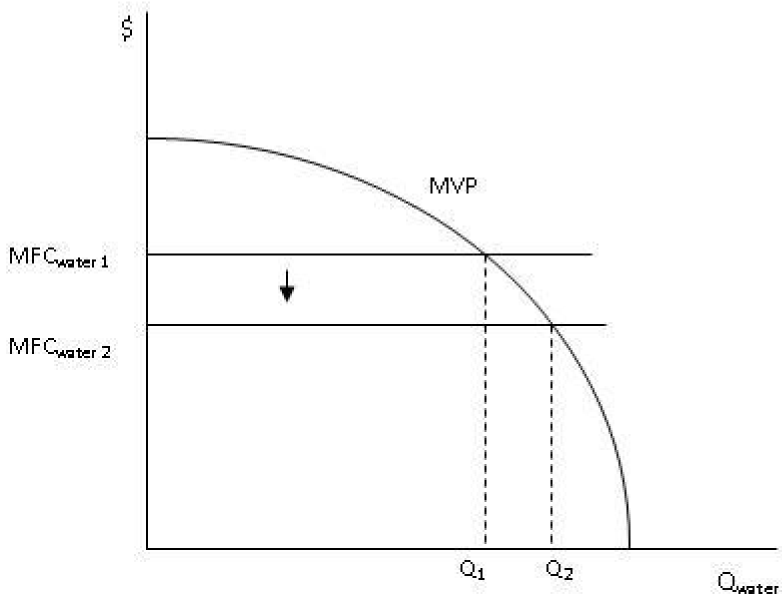
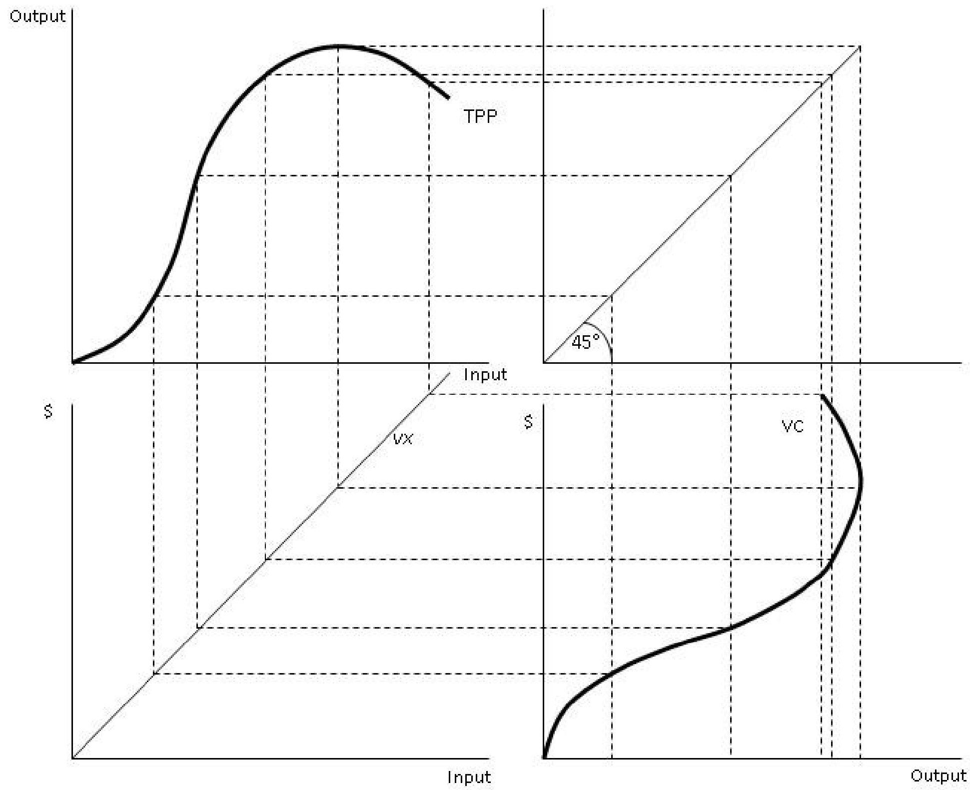


Figure 5. Implications of a reduction in marginal factor cost (MFC) due to the adoption of new technology

Output

To contrast the theory from the optimal level of input, the discussion turns to the optimal level of output or production. Producers are interested in maximizing their profits given their set of fixed constraints, e.g., land, labor, capital. Profits are calculated by subtracting the total costs from the total revenues. The total costs are made up of costs that are fixed and costs that vary with production. The total cost function related to a variable input is the inverse of the production function for that output (Debertin 1986). A visual representation of the relationship between the production function and the variable cost function can be represented in Figure 6. The variable cost function can be drawn graphically using the graph of the production function. One way to illustrate the graph of the variable cost function with inputs on the y-axis is to consider a mirror image of the production function over a 45 degree line from the origin. This will interchange the axes of the graph so that the x-axis is now the y-axis and vice versa. The x-axis of the production function represents amount of input applied, and the y-axis represents the amount of output that corresponds to that level of input. Once the axes have been switched, the x-axis now represents the level of output and the y-axis now shows the level of inputs.

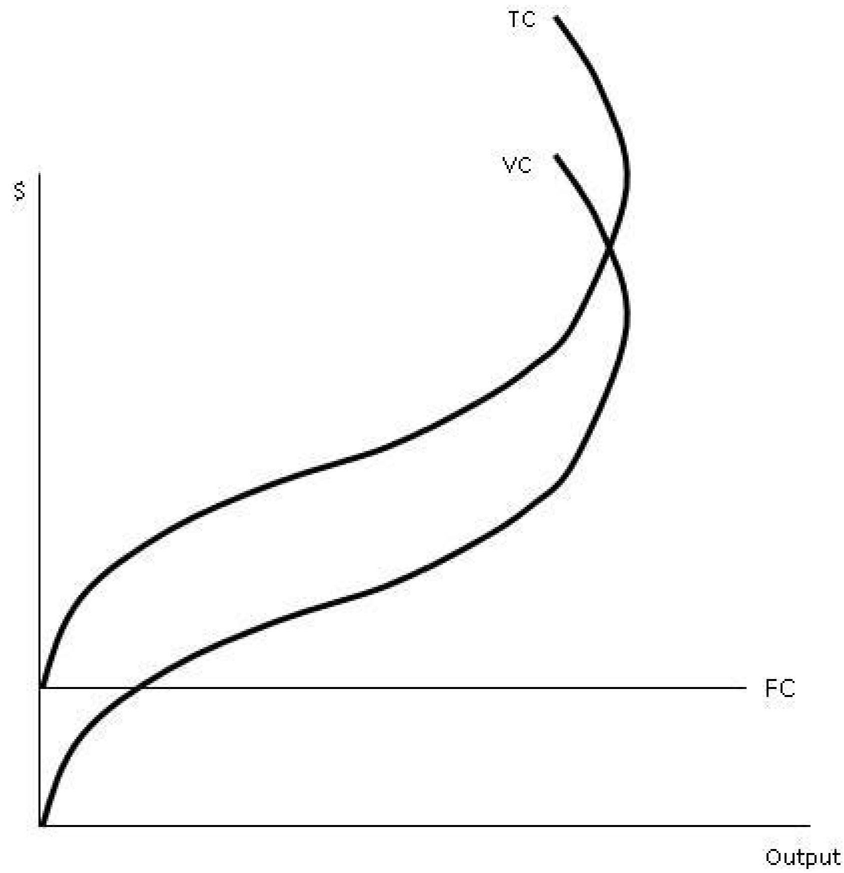
To express the level of inputs that are applied into costs, each level of input is multiplied by the market price of the input. This is shown in the lower left graph in Figure 6. The variable cost function graph now has the amount of output on the x-axis and the level of the costs associated with the inputs on the y-axis. The variable cost function starts to turn backwards after the maximum amount of output that can be physically obtained is reached. This occurs because the addition of any more inputs such as water, fertilizer, or herbicide will harm the crop and reduce the yield (Debertin 1986).



Source: Debertin (1986)

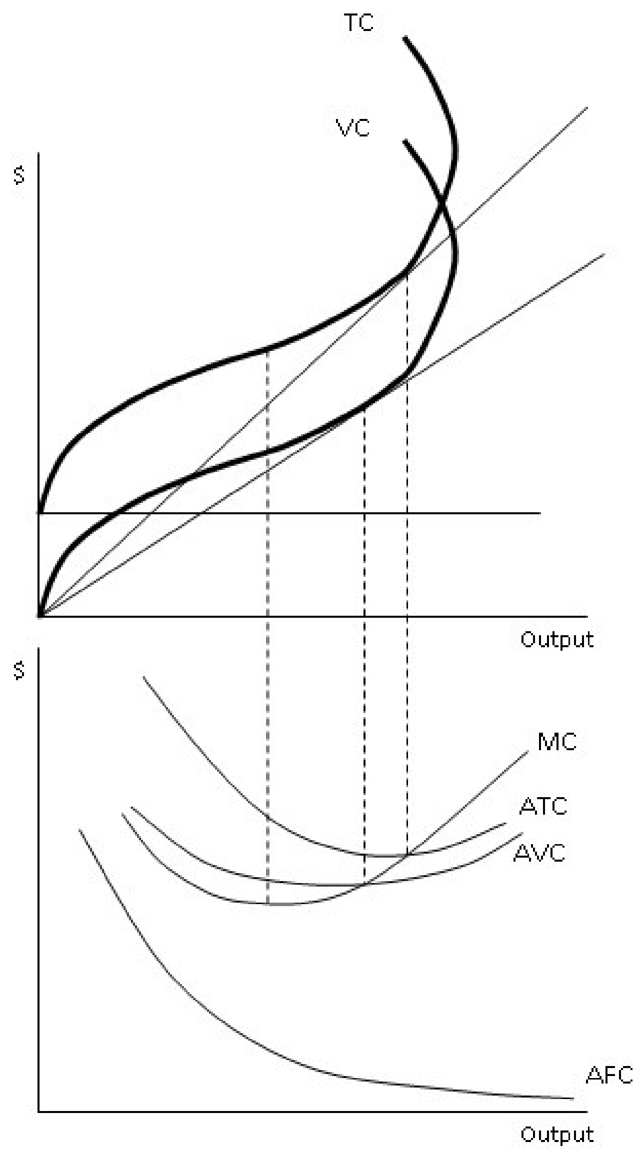
Figure 6. Relationship between production function and total variable cost function

The variable cost function can now be transformed into the total cost function by the addition of the fixed costs. This transformation will shift the variable cost function up from its beginning at the origin to beginning where the level of fixed costs intersects the y axis, which is shown in Figure 7.



Source: Debertin (1986)
Figure 7. Transformation of variable cost to total cost

To estimate the profit-maximizing level of output, the concept of the margin is reintroduced. The marginal cost curve represented graphically involves determining the location of the inflection point of the total cost curve. This point is the minimum point of the marginal cost curve. To draw the rest of the marginal cost curve, the minimum points of the average variable cost and the average total cost must be identified as well, as the point where the marginal cost curve intersects both of these points. The minimum point of the average variable cost is found by drawing a line from the origin that is tangent to the variable cost curve. The intersection of the tangent line and the variable cost occurs at the point where the average variable cost is the smallest. The minimum value of the average total cost is found by drawing a line that extends out of the origin and lays tangent to the total cost curve. The marginal cost curve can now be drawn on the graph where it intersects the minimum points of the average variable and average total cost, with its minimum point being at the same level of output as the inflection point of the total cost curve. A graphical representation of the relationship of the aforementioned cost functions is represented in Figure 8.



Source: Debertin (1986).

Figure 8. Graphical representation of marginal cost, average variable cost, average fixed cost, and average total cost as derived from the total cost

The profit-maximizing amount of output occurs where MR=MC due to the profit function being Profit = Total Revenue – Total Costs. When searching for a maximum or minimum, the first-order conditions are used. The first-order condition involves taking the first derivative of the objective function and setting it equal to zero, and solving for the corresponding level of output. To complete this task, the first derivative of the profit function with respect to y represented mathematically is: $\partial\prod/\partial y=\partial TR/\partial y-\partial TC/\partial y$, which becomes $\partial\prod/\partial y=MR-MC$. When using first-order conditions and setting the above equal to zero, the equation becomes MR – MC = 0, or MR = MC (Debertin 1986). Since agriculture is assumed to operate in a perfectly competitive market, the marginal revenue will be the market price of the output due to a constant price that is received for the output regardless of the level of production by any one producer and the additional amount of revenue that is received for each unit of output equals the price. The profit-maximizing condition for the output side is P=MR=MC. An illustration of the profit maximizing condition is shown in Figure 9 where P_y represents the market price of the commodity, and Q_y represents the level of output that maximizes profit.

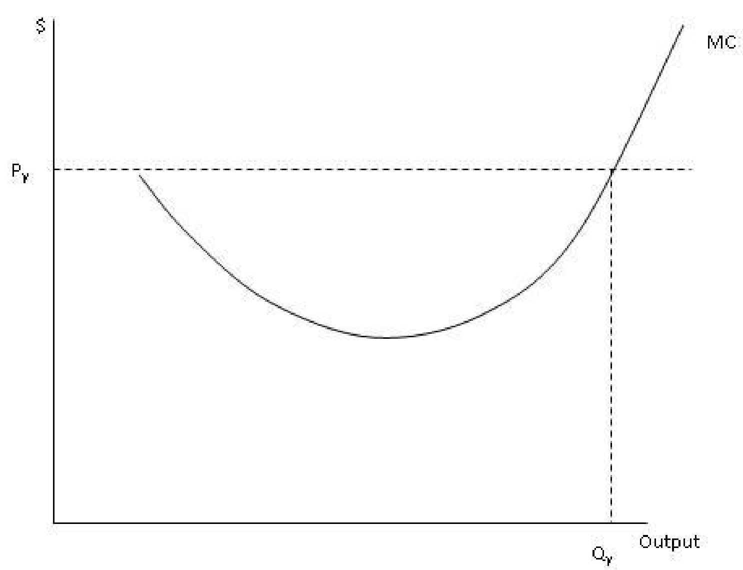


Figure 9. Profit-maximizing condition, output side

If a producer adopts a new technology, such as drip irrigation, the marginal cost is expected to shift. If the new technology is cost reducing, the marginal cost will shift from MC_1 to MC_2 as shown in Figure 10. As the marginal cost decreases, the profit maximizing level of output will change as well. In Figure 10, the amount of output that is produced increases from Q_{y1} to Q_{y2} due to a constant price received for the output, while the costs incurred decrease, leading to increased production that allows the producer to generate a maximum (more) profit.

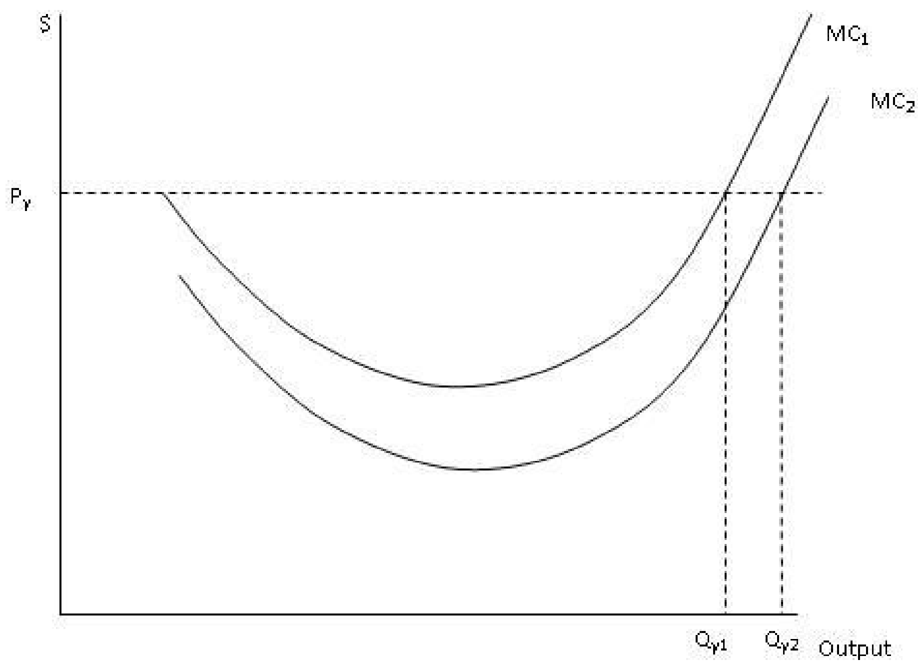


Figure 10. Implications of a decrease in marginal cost on quantity of output

These theoretical concepts are based just on the use and variable cost of an input to produce an output. Ignored is capital investment to switch to a new technology and other objectives the decision maker may have. However, once the investment decision is made, it is a sunk cost and not relevant in the decision of level of output to produce or similarly, level of input to use.

New Technology Implication

As demonstrated in the discussion for profit maximization based on optimal level of input to use and optimal level of output to produce, the solution is the same. Similarly, to explore economic incentives related to new technology such as an irrigation system that reduces the per unit cost of water, the incentive is to produce more output using more of the input (water for example).

Application of Theory

For this economic analysis of a new (alternative) technology related to irrigation, budgeting analysis is applied by comparing the per acre implications of drip irrigation to the traditional systems. In addition, a profit-maximizing quadratic programming (QP) model for the Lower Rio Grande Valley is applied where there is competition between irrigation systems and crops. The QP model is applied for alternative levels of water available to agriculture, focusing on when water becomes the most scarce resource and expected associated irrigation decisions.

METHODOLOGY

An evaluation of the economic viability of drip irrigation for the Lower Rio Grande Valley (LRGV) involves an array of economic tools. The methodology related to this thesis utilized partial budgeting procedures including creating new crop enterprise budgets for drip-irrigated crops, net present value analysis, and internal rate of return analysis. A quadratic programming model was also employed to provide insight on the impact of drip irrigation on cropping patterns in the LRGV under alternative water availability scenarios.

To gain insight on drip irrigation in South Texas, visits with producers and irrigation district managers were conducted. There is limited adoption of drip irrigation and it mainly occurs on vegetables and citrus. Vegetable growers utilizing drip irrigation primarily looked for improved fruit quality and conformity with growing under plastic mulch (Hill 2011). Irrigation districts viewed drip irrigation as a challenge due to frequency of applications and need to keep irrigation canals charged over long lengths of time (Hinojosa 2011). Although these ‘real-world’ field visits were helpful in understanding the parameters and concerns related to drip as compared to furrow or flood irrigation, there is little research, demonstration, or farm drip irrigation data for the region.

Crop Enterprise Budgets

Crop enterprise budgets were developed for crops identified by producers as most applicable to adoption of drip irrigation. Crops evaluated were high-value crops including oranges, grapefruit, onions, sugarcane, and cotton. The enterprise budgets were developed to provide estimates of the amount of revenue, expenses, and profit on a per acre basis by crop and system (Kay and Edwards 1999). The crop enterprise budgets developed by Texas AgriLife Extension Service (2012a) served as the base for the traditional irrigation system and were then modified to reflect the drip irrigation cost characteristics for the crops in the LRGV listed above. The enterprise budgets were constructed in Microsoft Excel consisting of two sets of columns which allowed for comparison between the conventional irrigation (flood, furrow) and the proposed irrigation (drip). Additional rows were then added to the budgets to allow for additional costs associated with the adoption of drip irrigation. These budgets can be found in Appendix A.

Yield Response

Through a review of literature, the yield responses to drip irrigation were estimated. The yield responses due to application of drip irrigation were calculated as a percent change of the conventional irrigated yields in the crop enterprise budgets (Texas AgriLife Extension Service 2012a) or from data in the study. These yield responses were then applied to the drip irrigation side of the newly-constructed crop enterprise budgets. Sugarcane yield in the LRGV increased by 38.9% as irrigation techniques shifted from flood irrigation to drip irrigation (Wiedenfeld et al. 2005). Enciso, Jifon, and Wiedenfeld (2007) reported that marketable onion yields on drip irrigation in the LRGV were about 26.1 tons per acre, which translates into a 20% increase in yield from the published crop enterprise budgets for flood-irrigated onions. However, there are published yield responses (Shock, Feibert, and Saunders 2005) of onions that show a 46.3 ton/acre yield from utilizing drip irrigation technology. The effects of drip irrigation on citrus in the LRGV have been published by Nelson et al. (2011), illustrating a 22.5% increase in grapefruit yield from drip irrigation compared to flood irrigation between 2005 and 2009. Since grapefruit and oranges are similar crops, the yield increase observed in grapefruit was used for oranges as well. The yield response of cotton to drip irrigation was assumed to be 20%[2]. As crop yields increase, certain per unit variable costs increase as well, such as harvest and processing. By constructing the new crop enterprise budgets in Excel, the costs that change as a result of a yield increase can be easily linked to the new yield.

Water Application Rate

The amount of water applied to crops using drip irrigation was also determined through a review of literature. The water applied to sugarcane in the LRGV decreased from 63 inches to 52 inches per acre, which is a 17.5% decrease (Wiedenfeld et al. 2005). The amount of water applied to drip-irrigated onions in the region was 15.8 inches according

[2] This 20% yield increase is a result of comparing the yield increases for the other crops in the region as drip irrigation was implemented. There is currently no literature published on the adoption of drip irrigation in the LRGV for use on cotton. The published studies available on drip irrigation for cotton occur in West Texas where yields increase by 27% over conventional furrow irrigation (Henggeler 1995).

to Enciso, Jifon, and Wiedenfeld (2007). This resulted in 53% less water applied to onions using drip irrigation compared to furrow irrigation as reported in the published crop enterprise budgets. Nelson et al. (2011) reported a 26.1% water savings with drip irrigation of grapefruit compared to traditional flood irrigation. The water savings realized from using drip irrigation on grapefruit were used as a proxy for the water savings observed for oranges grown in the LRGV since they are both perennial tree crops. Cotton was also assumed to have a 20% decrease in the amount of water applied to the crop based on the amount of water applied to other crops in the area. This 20% decrease was associated with an initial application of 12.5 inches of water to cotton in the area (Pennington 2012), resulting in 10 inches of water applied with drip irrigation. The reported decrease in the amount of water applied is a result of the drip irrigation technology having greater irrigation efficiency. Irrigation efficiency is defined as the ratio of water used by the plants to the amount of water that was delivered through the irrigation system minus the change in storage of water (Burt et al. 1997). As efficiency increases, less water is applied to crops per acre due to reduced losses to evaporation, run-off, and percolation.

Drip Irrigation Variable Costs

Through communication with producers in the area (Heller 2011, Hill 2011), it was concluded that they are currently utilizing similar irrigation systems in the LRGV as described for irrigating melons in the Crop Products Report (Texas AgriLife Extension Service 2012b). The machine described to irrigate melons includes a small diesel engine, pump, and media filters that are mounted on a flatbed trailer, which can then be transported from field to field. This system is attached to a manifold that distributes the water to the drip lines or tapes and is capable of irrigating 40 acre sections of land. The amount of labor used by the drip system according to the Crop Products Report (Texas AgriLife Extension Service 2012b) was 0.002 hours per hour of operation. The repair and maintenance costs were calculated in the same manner, using the values defined in the Crop Products Report (Texas AgriLife Extension Service 2012b). The cost of repair and maintenance was defined as $0.05 per hour of operation of the drip trailer system.

To calculate the aforementioned costs on a per acre basis, a conversion factor was applied using the information provided in the Crop Products Report (Texas AgriLife Extension Service 2012b). For each acre-inch of irrigation water applied to the 40 acre field, the system ran a total of seven hours due to the flow rate of the drip tape. The labor cost was calculated by multiplying 0.002 by seven to get the amount of labor associated with each acre-inch of water applied. That product was then multiplied by the total number of acre-inches applied to the crop to obtain the total hours of labor used per acre per year. The total labor cost was then calculated by multiplying the total hours of labor used by a wage rate of $7.50 per hour. The repair and maintenance cost per acre-inch of water applied was calculated by multiplying the cost of $0.05 per hour by seven hours as well. This value was then multiplied by the number of acre-inches of water that were applied per acre during the growing season to get the total cost of repair and maintenance per acre per year.

The fuel cost of the drip system was calculated using the fuel consumption rate also found in the Crop Products Report (Texas AgriLife Extension Service 2012b). The diesel engine that is mounted on the flatbed trailer to pump the water out of the canal, pipeline, or pond was estimated to use 1.2 gallons of diesel for each hour it runs (Texas AgriLife Extension 2012b). To calculate the total cost of the diesel fuel used, a drip cost calculator developed by the University of Delaware Cooperative Extension (2012) was applied. The type of pump found on the drip trailer system is capable of pumping 800 gallons per minute, or 48,000 gallons per hour. To determine the total amount of water pumped per gallon of diesel consumed, the total amount of water applied in an hour, 48,000 gallons, was divided by the fuel consumption rate per hour, 1.2. This resulted in a value of 40,000 gallons of water pumped per gallon of diesel fuel consumed. The total gallons of water applied to an acre were then estimated by multiplying the acre-inches of water applied by the total number of gallons in an acre-inch, 27,154. After determining the total amount of gallons of water applied, it was divided by 40,000, the water pumped rate per gallon of diesel, to determine the total amount of gallons of diesel that were used during the irrigating season. To determine the total cost of the diesel used, the total number of gallons of diesel was multiplied by the cost of diesel per gallon, $3.10 (Texas AgriLife Extension Service 2012a)

Shown in Table 3 are the variable costs associated with drip irrigation. Since the variable costs depend on the inches of water applied to the crops, the crop with the highest variable costs per acre is sugarcane, which has an application of 49 inches of water. Onions require the next highest amount of water at 15.7 inches. The lowest variable costs realized are for citrus and cotton. The citrus crops require 10.6 inches of water per year, while cotton requires 10 inches.

Table 3. Variable Costs Related to Drip Irrigation on a Per Acre Basis

Cost	Onion	Cotton	Sugarcane	Grapefruit	Orange
Fuel	$33.16	$21.04	$104.22	$22.40	$22.40
Labor	1.65	1.05	5.20	1.12	1.12
Repair/Maintenance	5.52	3.50	17.33	3.72	3.72
Total	60.20	25.59	117.23	27.62	27.62

Drip Irrigation Investment

The cost of the drip tape and installation varied for each crop. The main factor to consider when determining the cost of a drip system is the amount of space between drip lines. As the row spacing increases, the cost of the tape decreases due to fewer feet of drip tape needed per acre to irrigate the crops. Shown in Table 4 are the total investment costs for each crop separated by component.

Table 4. Total Drip Irrigation Investment Costs

Item	Onion	Cotton	Sugarcane	Grapefruit	Orange
Drip Trailer System[a]	$22,000	$22,000	$22,000	$22,000	$22,000
Drip Tape/Install[b]	51,656	26,200	42,637	26,560	26,560
Other Drip Materials[c]	13,219	-[d]	13,702	-[d]	
Total	86,875	48,200	78,339	48,560	48,560
Per Acre	2,172	1,205	1,958	1,214	1,214

Note: Each field is assumed to be 40 acres
[a]Texas AgriLife Extension Service (2012b)
[b]Netafim (2012); Irrigation Training and Research Center (1996)
[c]Toro (2011)
[d]Other drip materials not included in costs for cotton and grapefruit as all costs are present in the drip tape/install costs

The materials and installation cost for cotton was obtained from Enciso, Colaizzi, and Multer (2005). The total cost to install a system with drip lines spaced every two meters was $654.76 per acre in that particular study, which included the pump, filtration system, drip lines, and installation. The system with two meter spacing was chosen over the system utilizing one meter spacing based on the results of Enciso, Colaizzi, and Multer (2005). The cost of drip for the citrus crops, oranges and grapefruit, was obtained through communications with an LRGV citrus producer (Heller 2011). Drip irrigation in citrus is completed by laying thicker drip lines on the surface along the base of the trees as opposed to other crops, where drip lines are often buried. Placing the drip lines on the surface lowers the installation cost. The drip lines are assumed to have a useful life of ten years. The cost to install a drip system was on average about $665 per acre (Heller 2011). This cost only includes the pipes and drip lines, not the pump or filters. The drip trailer system required to supply the water to the drip lines is an additional $22,000.

The total cost to purchase and install a drip system for onions for a 40-acre field was estimated to be $86,875. The total cost was calculated through application of the University of Delaware Cooperative Extension Irrigation Cost Calculator (2012). The spacing of the rows was 40 inches (Enciso, Jifon, and Wiedenfeld 2007), and the average row length was assumed to be 500 feet. With this row spacing and length, applying the calculator indicated that there were 26 rows per acre. This information was used to calculate the amount of drip tape that was needed as well as the length of the manifold for each acre. The total amount of drip tape required per acre was 13,068 feet, with 137 feet of lay-flat pipe per acre to supply water to the drip tape. The cost of the drip tape and fittings were then obtained from the Netafim (2012) price list to determine the total cost per acre of $1,295.18. The price of the lay-flat supply pipe, which is used as the manifold, was taken from the Toro (2011) catalog and amounted to $306.69. The cost to install the drip tape by using a special implement to bury it was $20 per acre (Irrigation Training and Research Center 1996). The life of the drip tape was assumed to be one season for onions; however, there are some producers in the area that are able to collect and reuse the drip tape for a second season. Few producers collect the drip lines after each irrigation season with plans to use it a second season due to the level of expertise required to collect the tape and reinstall it (Pennington 2012).

The costs of installing the drip system for sugarcane were determined to be similar to the onions. The size of the field was assumed to be 40 acres with 500 foot rows spaced 60 inches (Wiedenfeld et al. 2005). This resulted in 17 rows per acre and 8,712 feet of drip tape per acre. The type of tape used for sugarcane was 10 mils thick and it was expected to last five years, or the life of the sugarcane. Sugarcane is a perennial crop which is assumed to be grown for five years on the same piece of land before it is replaced with another crop for rotation purposes. The total cost of the drip tape for the 40 acre field in question was $42,636.80 (Netafim 2012), and the cost of other materials needed to make the system functional summed to $35,701.90. The other materials include the lay-flat pipe, fittings, the drip trailer system, and the installation of the pipe. The total cost of the drip irrigation system was calculated to be $78,338.70 or $1,958.47 per acre.

The capital investment costs of the drip irrigation systems were then amortized over the life of the system to obtain an annual fixed cost for a producer to adopt a drip irrigation system. The interest rate of 6.69% used to amortize the investment in the irrigation technology represents the average intermediate agricultural lending rate in Texas during the fourth quarter of 2011 (Federal Reserve Bank of Dallas 2011). The drip trailer system was assumed to have a useful life of 15 years, the cotton drip system 10 years, the tape for the onions one year, the tape for the sugarcane five years, and the tape for the citrus 10 years. Shown in Table 5 are the amortized investment costs per acre for each of the crops proposed for potential adoption of drip irrigation in the LRGV.

Table 5. Amortized Drip Irrigation Investment Costs per Acre

	Onion	Cotton	Sugarcane	Grapefruit	Orange
Drip Trailer System	$59.21[a]	$59.21[a]	$59.21[a]	$59.21[a]	$59.21[a]
Drip Tape/Install	1,377.79[b]	91.93[c]	257.81[d]	93.19[c]	$93.19[c]
Other Drip Materials[e]	79.93[d]		82.85[d]		
Total Annual Equivalent	1,516.93	151.14	399.88	152.40	$152.40

Note: Each field in analysis is assumed to be 40 acres.
[a] Useful life of 15 years.
[b] Useful life of 1 year.
[c] Useful life of 10 years.
[d] Useful life of 5 years.
[e] Lay-flat supply pipe, drip tape fittings.

Budgeting Analysis

As discussed in the previous section regarding economic theory, the implications of the marginal use of water were examined, but as the capital investment is made in drip irrigation the focus is expanded to the total use of water. Due to the nature of the investment a budgeting analysis was utilized for this study. The crop enterprise budgets that were developed for the drip irrigation technology were compared with the base enterprise budgets of the current irrigation technology (flood or furrow) for each crop. A capital budgeting analysis was performed in which the crop enterprise budgets returns above specified costs[3] were compared. The results of this comparison were interpreted and analyzed using the net present value (NPV) which accounts for the time value of money by being able to compare the future cash flows once the drip irrigation system is in place as a present value. The magnitude and sign of each scenario's NPV provide insight on the economic feasibility of the investment (Barry et al. 2000). As the NPV increases in positive magnitude, the investment becomes more economically feasible. The NPV was calculated using the following equation:

(1) $$NPV = -IC + \sum_{i=1}^{n} \frac{NCF_n}{(1+r)^n} + \frac{TV_n}{(1+r)^n}$$

where *IC* represents the initial investment costs of drip irrigation; *NCF* represents the projected net cash flows of the crop associated with the drip irrigation; *r* represents the discount rate; *n* represents the life of the system; and *TV* represents the terminal value of the system (Barry et al. 2000). The investment costs for each crop have been previously defined in Table 4. The net cash flows of the crops were calculated using the newly-constructed crop enterprise budgets. The net cash flows are represented on the crop enterprise budgets as the returns above variable costs (RAVC) less the amortized investment costs for the drip system. The value that results from subtracting the

[3] The terminology returns above specified costs (RASC) is used in this thesis rather than returns above variable costs (RAVC) due to the presence of fixed drip investment costs in the calculation of returns.

investment cost is referred to as the return above specified costs (RASC). The RASC is used as the net cash flow value since producers evaluating drip irrigation are expected to be concerned with the short run. The shut-down point in the short run is defined as the point in which RAVC is equal to zero (Kay and Edwards 1999). The discount rate (r) used in the NPV calculation represents the opportunity cost of the capital used to invest in the drip irrigation technology (Rister et al. 2009). The enterprise budgets are constructed in a matter that does not account for the effects of inflation, so a real discount rate was used (Kay and Edwards 1999) To calculate the real discount rate, the following equation was used (Barry et al. 2000):

$$r = \frac{(1+r_N)}{(1+r_F)} - 1, \tag{2}$$

where r is the real discount rate; r_N is the nominal interest rate; and r_F is the inflation rate. The nominal interest rate used in this calculation was 6.69%, the average intermediate agricultural lending rate in Texas during the fourth quarter of 2011 (Federal Reserve Bank of Dallas 2011). The inflation rate of 2.48% was used in the calculation of the real interest rate. The inflation rate was calculated using the Other Machinery Index found in the Agricultural Prices report (U.S. Department of Agriculture 2011). Using Equation 2, the real discount rate calculates to 4.11%. The planning horizon, *n*, for the investment in drip irrigation was defined to be 10 years. This planning horizon leads to a positive terminal value of the drip trailer system due to the useful life being 15 years. The terminal value for the other portions of the capital investments will be zero. The drip irrigation system was depreciated using the straight-line method, which allowed for the terminal value of the drip trailer system to be calculated.

When completing this analysis for the flood-irrigated crops, there are no investment costs that are present. Therefore, the calculation of the NPV is just the projected RASC for a period of 10 years. The projected returns for the flood-irrigated crops are discounted using the same discount rate that was defined for drip irrigation. This allows for a comparison between the NPVs of flood and drip-irrigated crops.

Breakeven Yield Analysis

In addition to evaluating the net present value, a more traditional analysis of using crop enterprise budgets was completed. In this case, the expected net returns for a crop comparing traditional irrigation to drip irrigation were compared. This set of values also permits for the completion of breakeven analysis, or the calculation of the resulting yield in which the net returns are equal for both irrigation technologies.

The breakeven yields for the crops were calculated using goal seek in Microsoft Excel. Goal seek allows one variable to be changed by setting another value to a predefined level. The returns per acre for drip irrigation were set equal to the returns per acre of flood irrigation. The yield response was allowed to vary which allows for the costs that are related to the yield to change as well. As the yield responses are changed, the breakeven yield responses are generated by equating the returns per acre for both irrigation technologies.

Regional Agriculture Model

A regional analysis was completed which involved modifying and applying an optimization model developed by Robinson, Michelsen, and Gollehon (2010). The optimization model was solved using the General Algebraic Modeling System (GAMS) with the CONOPT solver, which finds the optimum point of a non-linear programming model (Brooke et al. 1998). The study area for the model includes several counties in the Rio Grande Valley, including Cameron, Hidalgo, Willacy, Starr, Kinney, Maverick, Webb, and Zapata. The objective of the model application was to maximize agricultural producers' net revenues in the LRGV given a set of constraints. The optimization model was updated with the current yields and costs found in the Texas AgriLife Extension Service (2012a) crop enterprise budgets for all crops identified in the model.

Since the previous model only included drip irrigation for melon crops, there were changes made to allow for the addition of drip-irrigated crops, including onions, cotton, citrus, and sugarcane. The yields and water usage defined by the newly constructed crop enterprise budgets were added to the model to reflect the yield, cost, and revenue responses to drip irrigation. Additional costs that result from adopting drip irrigation such as labor, fuel, and repair and maintenance were added to the table of costs present in the model. The annualized capital investment costs were also included in the model as part of the costs of the crops. Due to some farm benefits that are associated with historical yields (as opposed to yields that may change with drip irrigation), farm program payments were omitted from the original program. The uncertainty of the legislation of the new farm bill precludes any benefits that may change with the implementation of drip irrigation (Smith 2012).

Due to drip irrigation being a newer technology in the LRGV, historical yield data were unavailable. It was assumed that the historical yields of the drip-irrigated crops would be proportionate to the historical yields of the respective crops by the yield response percentage discussed earlier; therefore, the historical yields of the newly-added drip crops were added to the existing data by multiplying the percentage change of the yields by the historical yield for each crop. The yields of the newly-added drip crops were added to the model to include the drip crops in the variance-covariance matrix and have the ability to choose these crops in the solution.

The cost of water for each of the drip-irrigated crops was also modified in the cost table to reflect the difference in water usage as drip irrigation was adopted. The resulting water costs were calculated by multiplying the price of water per acre-inch, $1.67 (Texas AgriLife Extension 2012a), by the acre-inches of water required by the drip-irrigated crops. Another aspect of the model involves the available amount of water diverted from the Rio Grande for irrigation use. The level of water available in the model was determined by published historical water use surveys from the Texas Water Development Board (2012). The total amount of water available for agriculture in the region was calculated by summing the amount of surface water used for irrigation purposes in the counties included in the model.

Historical prices were also updated to include a more recent period of years. This allowed for the variance-covariance matrix to be calculated with relevant historical revenues. The prices paid index and prices received index were also updated with more recent data to account for inflation that has occurred since the model was constructed.

The model was solved using the CONOPT solver in GAMS, which reported the optimal cropping mixes based upon soil type, irrigation type, and irrigation level for four alternative risk aversion levels. The risk aversion levels defined to represent the producers in the region ranged from risk loving, α=0, to risk averse, α=0.0000001.

The formulation of the model used in this thesis is the same as published in Robinson, Michelsen, and Gollehon (2010). The summation notation for the model is shown as:

(3)"Max $\sum_i \sum_j \sum_k \sum_l \left(EREV_{ijkl} * X_{ijkl} - \alpha \sum_j \sum_l Z_{jl} \mathrm{V_{jl}Z_{jl}}\right)$

(4)$\sum_i \sum_k X_{ijkl} \leq Z_{jl}$

(5)$\sum_i \sum_j \sum_k \sum_l WATERUSE_{ijkl} * X_{ijkl} \leq WATERRHS$

(6)$\sum_j \sum_k \sum_l X_{ijkl} \leq SOILSRRHS_i$

(7)$\sum_j \sum_k \sum_l X_{i\text{"}sugarcane\text{"}kl} \geq MINMILLFLOW$

(8)$\sum_j \sum_k \sum_l X_{i\text{"}sugarcane\text{"}kl} \leq GRINDRIGHTS$

(9)$\sum_k \sum_l X_{i\text{"}cotton\text{"}kl} - \sum_j \sum_k \sum_l X_{i\text{"}feedgrains\text{"}kl} \leq 0$

(10)$\sum_k \sum_l X_{i\text{"}sugarcane\text{"}kl} - 0.2 * \sum_j \sum_k \sum_l X_{i\text{"}cotton\text{"}kl} \leq 0$

$(11) \sum_j \sum_k \sum_l X_{i"citrus"kl} = ORCHARDS$

$(12) X_{ijkl} \geq 0$ " (Robinson, Michelsen, and Gollehon 2010).

The objective function represented by Equation (3) of the model maximizes the net revenue discounted for risk. Risk is accounted for in the model using the method described by Freund (1956) where a risk aversion coefficient is multiplied by the variance of the historical income and then subtracted from the net revenue in the objective function. This penalizes risky cropping practices, such as planting all acres in high-value/high-risk crops. Equation (4) is an identity in which the sum of the soil resources and irrigation technologies is less than or equal to that available. The amount of water used by all the crops in the model is constrained by the total amount of water available for use by Equation (5). The total acreages of the crops in the model for each different soil type is constrained in Equation (6) to be less than or equal to the total amount of acres available for agricultural production in each soil type. Equations (7) and (8) represent the constraints related to the amount of sugarcane that can be produced according to the sugar mill capacity. Crop rotations in the area are represented by Equations (9) and (10) in which cotton and feed grains are on a one-year rotation pattern and cotton and sugarcane are on a five-year rotation. The total acreage of citrus is fixed in the model by application of Equation (11). Citrus is a perennial crop, meaning that once it is established, it will remain fixed over the life of the orchard. Equation (12) is a non-negativity constraint to ensure the results of the model are positive.

Sensitivity Analyses

With the regional model, there is the opportunity to evaluate expected effects of alternative assumptions. Due to the very limited amount of farm level data, this research employs sensitivity analyses across alternative drip irrigation yields as well as water use levels in conjunction with total water available to agriculture to provide insight to decision makers. Expected yield and water use along with water available for the region are varied using predefined levels to determine returns above variable costs for each input level.

Five different sensitivity scenarios were created to compare with the results of the base scenario. The first scenario assumes constant increases in yield of 20% and water savings of 20 % for all crops when compared with the conventionally-irrigated crops. Scenario two maintains a 20% increase in yield for all drip-irrigated crops, but increases the water savings to 30%. The third scenario assumes a 30% increase in yield for all crops while realizing a 20% decrease in the amount of water used. Scenario four represents the base yield of the assumed base drip-irrigated crops with no water savings realized. Scenario five decreases the water savings of the onions on drip irrigation from 53% to 20% of the water use of furrow-irrigated onions, while keeping everything else the same.

These scenarios are tested at different levels of water available to agricultural production that have been observed in the LRGV (Texas Water Development Board 2012). The levels of water for the past 35 years were sorted from least to greatest and four different levels were chosen by dividing the amounts of annual water use into four segments and then finding the mean of each segment.

Another type of sensitivity analysis involved the cost of delivery of water per acre-inch. Six different levels of water costs were defined, which ranged from $2 to $40 per acre-inch. By varying the delivery cost of the water in the regional model, the estimated effects of alternative delivery costs on the choice of irrigation technology were simulated.

The results of these analyses will "help develop insights into system behavior which in turn can be used to guide the development of effective plans and decisions" (Geoffrion 1976). The plans and decisions that will take place as a result of the sensitivity analyses will allow producers and their stakeholders to make more informed decisions regarding the investment in an alternative irrigation system such as drip irrigation. There are multiple factors affecting such decisions, including outlook for irrigation water with the threat of drought, potential impacts of global climate change, farm policy, and overall demand for agricultural commodities.

The shadow price of the water in the regional agricultural model will also be analyzed. With the model being solved using GAMS, the calculation of the shadow price is part of the output. The range of validity is smaller in GAMS when compared to other optimization programs because GAMS only gives the shadow price of an additional unit. The range of validity of the shadow price is important because it provides the amount of units where the shadow price is the same as a constraint is relaxed.

RESULTS

Using the methodology described earlier, an analysis of the economics of the adoption of drip irrigation is presented in this section. The results of this study are insightful for LRGV area producers interested in the economic implications of adopting drip irrigation. The results examine drip irrigation from a capital budgeting viewpoint as well as from a regional modeling aspect. Alternate scenarios are also presented to represent implications of the sensitivity of results to water availability, yield effect, and water application rate.

Capital Budgeting

Applying basic capital budgeting techniques, this section addresses the returns above variable costs, net present value, and estimates the breakeven crop yields.

Returns Above Specified Costs

The per acre returns above specified costs (RASC) based on application of the crop enterprise budgets (Texas AgriLife Extension Service 2012a) were calculated for each crop for the current method of flood irrigation and the proposed adoption of drip irrigation under the base case for drip irrigation described earlier. Shown in Table 6 are the RASCs per acre for each crop by the type of irrigation technology utilized. Only citrus was shown to be more economically favorable with drip irrigation than with flood irrigation. Onions produced the largest difference between RASCs for flood and drip.

Flood irrigation on onions produced an RASC of $1,492.10 per acre, while the RASC of drip irrigation was $556.47 per acre, resulting in a deficit of $935.63 per acre between the irrigation techniques. Cotton irrigated by flood irrigation had an RASC of $245.51 per acre which was $48.74 greater per acre than drip-irrigated cotton which had an RASC of $196.77 per acre. Sugarcane also had a deficit between the RASC of flood and drip irrigation, which was $86.17 per acre. The flood-irrigated sugarcane had an RASC of $142.51 per acre, while drip-irrigated sugarcane had an RASC of $56.34 per acre. Grapefruit and oranges both had drip as a positive change over flood irrigation. The RASC of drip-irrigated grapefruit per acre, $1,909.03, was $420.91 greater than the $1,488.12 RASC of flood-irrigated grapefruits per acre. The drip-irrigated oranges produced an RASC of $714.36 per acre, which was $199.43 greater than the $514.93 RASC of flood-irrigated oranges per acre.

Table 6. Returns Above Specified Costs Results for the Adoption of Drip Irrigation per Acre [a]

Crop	Flood Irrigation	Drip Irrigation	Change From Flood
Onion	$1,492.10	$556.47	-$935.63
Cotton	$245.51	$196.77	-$48.74
Sugarcane	$142.51	$56.34	-$86.17
Grapefruit	$1,488.12	$1,909.03	+$420.91
Orange	$514.93	$714.36	+$199.43

Source: Texas AgriLife Extension Service (2012a)
[a] Base case for drip irrigation where drip is characterized by specifics of less water and higher yield

The next step in the process of comparing flood irrigation and drip irrigation is to analyze the implications of investment over time.

Net Present Value

When considering a capital investment, the projected returns of the investment over the life of the investment are usually considered instead of looking at the returns of the investment for one year. To complete this task, the net present value (NPV) of the RASC was calculated for each crop as outlined in the methodology. Table 7 reports the NPVs of each of the crops for flood irrigation and drip irrigation over a ten-year period for the drip irrigation base case. As with the RASC, the NPV of irrigating crops with flood irrigation was greater than drip irrigation for onions, cotton, and sugarcane. The NPV of onions irrigated with drip was $8,036.97 less than flood-irrigated onions having an NPV of $3,999.27. The NPV of cotton was $256.44 less using drip irrigation as compared to flood irrigation, resulting in an RASC of $1,724.01. When drip irrigation is considered for sugarcane, the NPV result was $738.15, which was $411.45 less than the NPV of flood-irrigated sugarcane.

The NPV of the citrus crops were greater utilizing drip irrigation instead of flood irrigation. The resulting NPV of grapefruit irrigated by drip was $1,909.03, which was $420.91 greater than the NPV of flood-irrigated grapefruit. The NPV of drip-irrigated oranges was $199.43 greater than the NPV of flood-irrigated oranges resulting in an NPV of $714.36.

Table 7. Net Present Value of Returns Above Specified Costs for the Adoption of Drip Irrigation per Acre[a]

Crop	Flood Irrigation	Drip Irrigation	Change from Flood
Onion	$12,036.24	$3,999.27	-$8,036.97
Cotton	1,980.45	1,724.01	-256.44
Sugarcane	1,149.60	738.15	-411.45
Grapefruit	12,004.18	15,537.40	+3,533.22
Orange	4,153.78	5,900.41	+1,746.63

[a] Base case for drip irrigation where drip is characterized by specifics of less water and higher yield

Breakeven Yield Analysis

As shown in Table 6, the RASC of drip-irrigated onions, cotton, and sugarcane are lower than their flood-irrigated counterparts. This is largely attributed to the investment in the drip irrigation technology which is required to adopt the alternative irrigation technology even though there is an expected yield increase and reduction in water use. There are many unknowns related to drip irrigation so a useful exercise is to calculate how much crop yield would have to increase to have equal RASC for drip and flood irrigation. The yields required by each crop to obtain the same RASC as the flood-irrigated crop are shown in Table 8.

Table 8. Breakeven Yield Responses per acre Required by Crop to Equalize Drip RASC with Flood RASC

Crop	Original Yield Response	Breakeven Yield Response	Percent Change
Onion	20% (1,080 sacks)	55% (1,393.97 sacks)	+35%
Cotton	20% (990 lbs.)	28% (1,056 lbs.)	+8%
Sugarcane	39% (69.5 tons)	48% (74 tons)	+9%

Onions were defined to have a 20 percent yield response to drip irrigation to produce 1,080 sacks per acre in the analysis; however due to investment costs for drip tape each season; the resulting breakeven yield response was greater and calculated to be 55 percent. This results in a 35 percent increase in yield response for onions above that assumed in the study for drip irrigation. Cotton and sugarcane both had more reasonable breakeven yield responses. For the RASC of drip-irrigated cotton to equal that of the flood-irrigated cotton, the yield would have to increase an additional eight percent to 1,056 pounds of lint produced per acre. Drip-irrigated sugarcane would need to produce five and one-half more tons per acre than the base assumption, resulting in a yield response of 48 percent in order to have an RASC for drip that is the same as flood-irrigated sugarcane.

Regional Agriculture Model

Following the methodology described earlier, a GAMS optimization model developed by Robinson, Michelsen, and Gollehon (2010) was updated using current data and modified to include drip-irrigated crops.

Baseline Results

The results of application of the GAMS model estimates cropping patterns for the region across varying risk aversion levels. Shown in Table 9 are the current cropping pattern results across risk aversion levels ranging from α=0 (no risk) to α=0.0000001 (risk averse). The current cropping pattern includes no drip irrigation on row crops or vegetables. The only crops utilizing drip irrigation in the area currently are melons such as honeydew, cantaloupe, and watermelons.[4]

Table 9. Baseline Cropping Pattern in Acres Using Current Irrigation Methods for All Levels of Risk Aversion[a]

	Risk Aversion Levels[b]			
Crop	0.00000000	0.00000005	0.00000008	0.00000010
Bell Pepper, Flood	0	1,931	3,495	3,689
Broccoli, Flood	0	14,798	11,713	9,795
Cabbage, Flood	172,014	48,436	29,779	23,294
Carrot, Sprinkler	2,500	2,500	2,500	2,427
Honeydew, Drip	25,000	3,241	2,321	2,058
Watermelon, Drip	0	0	1,329	2,223
Watermelon, Flood	0	21,759	21,350	20,719
Corn, Flood	0	7,387	20,701	23,280
Cotton, Flood	0	120,965	135,677	138,542
Cotton, Dryland	150,000	29,034	14,322	11,458
Sorghum, Flood	0	221,487	237,976	243,680
Sorghum, Dryland	150,000	0	1	2
Sugarcane, Flood	30,000	30,000	30,000	30,000
Orange, Flood	8,500	8,500	8,500	8,500
Grapefruit, Flood	18,500	18,500	18,500	18,500
Flood	229,014	493,763	517,691	519,999
Drip	25,000	3,241	3,650	4,281
Dryland	300,000	29,034	14,323	11,460
Total	554,014	526,038	535,664	535,740
Available Water at Reservoir	900,000	900,000	900,000	900,000
Available Water to Producers	672,200	672,200	672,200	672,200
Water Applied	672,200	672,200	652,800	634,300
Unused Water	0	0	19,400	37,900
Gross Income ($Million)	1,881.2	924.6	758.5	692.6
Net Income ($Million)	987	425.8	328.5	292.3

[a] Only drip irrigation is for crops already in place.
[b] Levels of risk aversion increase from left to right.

[4] Across the risk aversion levels, this study acknowledges the results published in Robinson, Michelsen, and Gollehon (2010) and works with α=0.00000008 as well. With the consideration of risk aversion versus no risk aversion, cropping patterns adjust from the higher-value, more risky crops of vegetables to greater irrigated acres of field crops. The net economic impact is estimated where net returns above specified costs decline from $987 million to $293 million.

Shown in Table 10 are the baseline results across varying levels of risk aversion after drip irrigation is incorporated into the model for onions, cotton, sugarcane, and citrus. The baseline scenario of the model incorporates the yield response and water usage described in the methodology. The amount of water available to be diverted for agricultural purposes was constrained to 900,000 acre-feet for the baseline scenario to represent the overall average amount of water diverted for the past 28 years (Texas Water Development Board 2012). The model accounts for water losses that occur from the time the water is diverted to the time the water reaches the field (i.e., delivery/transport losses) and amounts to about a 25 percent reduction.

The baseline results with drip irrigation incorporated reported in Table 10 show that as producers become exceedingly more risk averse, irrigation will be utilized to account for this risk as well as a movement from vegetables to field crops. This is shown as the amount of dryland crops planted and harvested decrease from 299,998 acres with no risk aversion to 9,652 acres for the most risk averse producers, while irrigation increases from 205,022 acres using flood irrigation to 470,000 acres, and from 52,000 acres of drip irrigation to 56,106. As risk aversion levels increase from $\alpha=0.00000000$ to $\alpha=0.00000010$, producers are also less likely to plant riskier, high-value crops such as cabbage. The acres of planted cabbage decline from 175,023 acres to 23,659 acres as risk aversion levels increase in the model. The gross income and net income for the region are also reported in Table 10 in millions of dollars. As risk aversion levels increase, it can be shown that both the gross and net incomes decrease due to planting less high-value crops, while incurring additional costs by irrigating less risky crops. From no risk aversion to a risk aversion level having an α=0.00000005, the gross income decreased from $1.9147 billion to $979 million, while the net income decreased from $1.0054 billion to $446.8 million. As risk aversion levels increase, the gross and net incomes do not decrease as rapidly as compared to the decline from no risk aversion to the introduction of risk aversion. The gross income decreases to $793 million, while the net income decreases to $344 million at a risk aversion level of α=0.00000008.

Following the results of Robinson, Michelsen, and Gollehon (2010), the risk aversion level of α=0.00000008 was used to represent the risk preferences of LRGV producers as it best represented the current cropping practices in the area for the study period in their report. Having a risk aversion level that represents producers in the area allows for additional analyses to be performed including the implications of the availability of water, differences in yield responses and water usage, and implications of water delivery costs for the drip-irrigated crops.

Table 10. Baseline Cropping Patterns in acres for All Levels of Risk Aversion with Drip Alternative[a]

	Risk Aversion Levels[b]			
Crop	0.00000000	0.00000005	0.00000008	0.00000010
Bell Pepper, Flood	0	1,951	3,377	3,537
Broccoli, Flood	0	14,652	10,814	8,857
Cabbage, Flood	175,023	48,882	29,996	23,659
Carrot, Sprinkler	2,500	2,500	2,500	2,407
Honeydew, Drip	25,000	3,192	2,304	2,029
Onion, Drip	0	2,315	1,467	1,188
Watermelon, Drip	0	0	1,061	1,965
Watermelon, Flood	0	21,808	21,635	21,006
Corn, Flood	0	4,308	16,465	18,066
Cotton, Drip	0	19,923	13,956	14,480
Cotton, Flood	0	106,157	129,609	125,868
Cotton, Dryland	149,999	23,920	6,435	9,652
Sorghum, Flood	0	228,246	241,547	248,451
Sorghum, Dryland	149,999	0	0	0
Sugarcane, Drip	0	12,067	8,671	9,444
Sugarcane, Flood	29,999	17,934	21,329	20,556
Orange, Drip	8,500	8,500	8,500	8,500
Grapefruit, Drip	18,500	18,500	18,500	18,500
Flood	205,022	443,938	474,772	470,000
Drip	52,000	64,497	54,459	56,106
Dryland	299,998	23,920	6,435	9,652
Total	557,020	532,355	535,666	535,758
Available Water at Reservoir	900,000	900,000	900,000	900,000
Available Water to Producers	672,200	672,200	672,200	672,200
Water Applied	672,200	672,200	640,800	616,700
Unused Water	0	0	31,400	55,500
Gross Income	1914.7	979	792.8	724.5
Net Income	1005.4	446.8	343.6	307.1

[a]Expand drip irrigation beyond what has been established by including as an alternative for cotton, onions, sugarcane and citrus.
[b] Levels of risk aversion increase from left to right.

Impact of Water Availability

Since the amount of water available in the LRGV region for agricultural use varies, two additional values besides the base value of 900,000 acre-feet were used as constraints on the amount of water available. The values identified were 650,000 acre-feet to represent reduced availability of water, and 1,250,000 acre-feet to represent increased water availability. These values are based upon the historical amount of available water in the LRGV (Texas Water Development Board 2012) and provide insight on the cropping patterns and drip irrigation adoption. Shown in Table 11 are the acreages of each crop and irrigation technology at a risk level of α=0.00000008.

The cropping patterns that result from having varying levels of water illustrate producers' expected response.[5] As the level of available water decreases, producers have to adjust from flood and drip-irrigated crops to more dryland crops. However, drip-irrigated acres were fairly consistent across the base and reduced water availability scenarios. Producers also leave an additional 63,775 acres of the 625,120 acres available for production unplanted as available water decreases. This can be attributed to the low productive soil category.

As available water increases from 900,000 to 1,250,000 acre feet, producers were shown not to change their cropping patterns, planting the same acreages of each crop utilizing

[5] The analysis related to the available water assumes that producers are informed before the crop year of water available for irrigation. This knowledge allows them the opportunity to make appropriate adjustments in crop selection and land preparation.

the same irrigation technology. An explanation for the same cropping patterns for the base amount of water available and an additional amount of water available is due to the optimization of the model. The solution with the base amount of water is the solution which maximizes the net revenue less the specified costs. As additional water is available in the model the solution does not change because the net revenue is already maximized. There are land capability classes included in the model where farmers are reluctant to expand irrigation.

As the amount of water available for irrigation decreases, the gross and net incomes of the area decrease as well. The gross income for the region decrease from $793 million to $716 million, while the net income decreased from $344 million to $318 million. The basic regional results do not change as additional water is available above 900,000 acre-feet. Therefore, the following results will not address the additional water scenario.

Table 11. Cropping Patterns in Acres for Base Yield/Water Usage, Risk Aversion Level of α=0.00000008

Crop	Reduced Water[a]	Base[b]	Additional Water[c]
Bell Pepper, Flood	1,635	3,377	3,377
Broccoli, Flood	5,086	10,814	10,814
Cabbage, Flood	29,287	29,996	29,996
Carrot, Sprinkler	2,500	2,500	2,500
Honeydew, Drip	2,478	2,304	2,304
Onion, Drip	1,445	1,467	1,467
Watermelon, Drip	2,329	1,061	1,061
Watermelon, Flood	20,193	21,635	21,635
Corn, Flood	0	16,465	16,465
Cotton, Drip	11,280	13,956	13,956
Cotton, Flood	98,882	129,609	129,609
Cotton, Dryland	39,837	6,435	6,435
Sorghum, Flood	202,389	241,547	241,547
Sorghum, Dryland	0	0	0
Sugarcane, Drip	9,417	8,671	8,671
Sugarcane, Flood	20,583	21,329	21,329
Orange, Drip	8,500	8,500	8,500
Grapefruit, Drip	18,500	18,500	18,500
Flood	378,055	474,772	474,772
Drip	53,949	54,459	54,459
Dryland	39,837	6,435	6,435
Total	471,841	535,616	535,616
Available Water at Reservoir	650,000	900,000	1,250,000
Available Water to Producers	485,500	672,200	933,600
Water Applied	485,500	640,800	640,800
Unused Water	0	31,400	292,800
Gross Income (Million Dollars)	716.1	792.8	792.8
Net Income (Million Dollars)	317.6	343.6	343.6

[a] 650,000 acre-feet of water available at reservoir.
[b] 900,000 acre-feet of water available at reservoir.
[c] 1,250,000 acre-feet of water available at reservoir.

Sensitivity Analyses

Due to the limited amount of data regarding yield response and water saving for drip irrigation in the LRGV, five different scenarios were developed to provide insight on sensitivity of the estimates. The results presented in the following sections illustrate the expected effects of varying levels of drip-irrigated yield and water usage on the cropping patterns in the area.

Scenario 1 - 20% yield increase, 20% water savings

Scenario 1 utilizes a 20 percent drip yield increase over the flood irrigation yield and water savings of 20 percent for drip compared to flood irrigation for all crops. This allows for analysis of the crops using a different amount of water than identified in the literature as is the case for onions, sugarcane, and grapefruit. Cotton is the only crop for which these data remain unchanged from the base for this scenario.

The results presented in Table 12 illustrate the effect of Scenario 1 on the cropping pattern and economic returns for the base and reduced availability of irrigation water. The cropping pattern for the base amount of water of 900,000 acre-feet when compared with the base scenario in Table 11 show that flood-irrigated acres increased from 474,772 to 483,435, while drip-irrigated acres decreased from 54,459 to 42,727. The amount of dryland acres increased from 6,435 to 9,502 as a result of the yield response and water usage scenario.

As the amount of water available to producers was reduced to 650,000 acre feet, the cropping patterns estimated by application of the agriculture model suggest that the acreages of flood-irrigated crops increased to 386,122 from 378,055 when compared to the cropping patterns for reduced availability of water in Table 11. Acreages for drip-irrigated and dryland crops both decreased as a result of the scenario. The drip-irrigated acreages declined from 53,949 to 46,111 acres, while dryland acres declined slightly from 39,837 to 39,608.

For Scenario 1, the gross and net incomes can be compared with the base scenario in Table 11. With a consistent 20 percent yield response to drip irrigation, while realizing a 20 percent water savings, the gross income decreases from $793 million in the base scenario with 900,000 acre-feet of water available to $788 million. As the amount of available water is reduced, the gross income declines to $709 million in Scenario 1 from $716 million in the base scenario (Table 11). The net income decreases as well when comparing Scenario 1 with the base scenario. With the base amount of water available, the net income decreases from $344 million to $342 million. As water is constrained in the model, the net income decreases from $318 million in the base scenario to $314 million in Scenario 1.

The gross income and net income are lower in Scenario 1 than for the base drip irrigation scenario due to lower yield responses and water savings. With decreased water savings realized, the irrigation costs are greater in Scenario 1. As Scenario 1 is implemented, sugarcane and citrus have lower yield responses to drip, thereby decreasing the revenues received for those crops.

Table 12. Cropping Patterns in acres for Scenario 1, Risk Aversion Level of α=0.00000008[a]

Crop	Reduced Water[b]	Base Water[c]
Bell Pepper, Flood	1,691	3,445
Broccoli, Flood	5,202	11,603
Cabbage, Flood	29,395	29,770
Carrot, Sprinkler	2,500	2,500
Honeydew, Drip	2,460	2,339
Onion, Drip	1,287	1,345
Watermelon, Drip	2,145	1,370
Watermelon, Flood	20,395	21,291
Corn, Flood	0	20,175
Cotton, Drip	8,868	10,673
Cotton, Flood	101,524	129,825
Cotton, Dryland	39,608	9,502
Sorghum, Flood	202,266	237,327
Sorghum, Dryland	0	0
Sugarcane, Drip	4,351	0
Sugarcane, Flood	25,649	29,999
Orange, Drip	8,500	8,500
Grapefruit, Drip	18,500	18,500
Flood	386,122	483,435
Drip	46,111	42,727
Dryland	39,608	9,502
Total	471,841	535,664
Available Water at Reservoir	650,000	900,000
Available Water to Producers	485,500	672,200
Water Applied	485,500	652,900
Unused Water	0	19,300
Gross Income ($Million)	709.4	788
Net Income ($Million)	314	341.8

[a]Scenario 1 is assuming 20% yield increase and 20% water savings for drip irrigation compared to flood irrigation.
[b] 650,000 acre-feet of water available at reservoir.
[c] 900,000 acre-feet of water available at reservoir.

Scenario 2 - 20% yield increase, 30% water savings

Scenario 2 represents a positive yield response to drip irrigation of 20 percent while the drip-irrigated crops are utilizing only 70 percent as much water as with flood-irrigated counterparts. This scenario illustrates the effects of an increase in water savings due to the adoption of drip irrigation resulting in greater water savings for sugarcane, citrus, and cotton as compared to the base drip irrigation scenario.

The results shown in Table 13 show the effect on the cropping patterns as Scenario 2 is implemented. The results for Scenario 2 compared with the results for the base drip irrigation scenario for 900,000 acre-feet of water available in Table 11 show that the amount of flood-irrigated acres increased from 474,772 to 483,280 and dryland acres increased from 6,435 to 9,041 acres. The acres utilizing drip irrigation decreased from 54,459 to 43,345.

Table 13. Cropping Patterns in Acres for Scenario 2, Risk Aversion Level of α=0.00000008[a]

Crop	Reduced Water[b]	Base Water[c]
Bell Pepper, Flood	1,781	3,448
Broccoli, Flood	5,504	11,592
Cabbage, Flood	29,564	29,766
Carrot, Sprinkler	2,500	2,500
Honeydew, Drip	2,448	2,338
Onion, Drip	1,335	1,349
Watermelon, Drip	2,072	1,360
Watermelon, Flood	20,481	21,302
Corn, Flood	0	20,178
Cotton, Drip	14,365	11,137
Cotton, Flood	99,451	129,822
Cotton, Dryland	36,184	9,041
Sorghum, Flood	201,657	237,332
Sorghum, Dryland	0	0
Sugarcane, Drip	9,350	161
Sugarcane, Flood	20,650	29,840
Orange, Drip	8,500	8,500
Grapefruit, Drip	18,500	18,500
Flood	379,088	483,280
Drip	56,570	43,345
Dryland	36,184	9,041
Total	471,842	535,666
Available Water at Reservoir	650,000	900,000
Available Water to Producers	485,500	672,200
Water Applied	485,500	647,700
Unused Water	0	24,500
Gross Income ($Million)	718.2	788.2
Net Income ($Million)	316.4	342

[a]Scenario 2 is assuming 20% yield increase and 30% water savings for drip irrigation compared to flood irrigation.
[b] 650,000 acre-feet of water available at reservoir.
[c] 900,000 acre-feet of water available at reservoir.

As the amount of water available in the model was restricted to 650,000 acre-feet, flood-irrigated acres increased to 379,088 acres when compared to the base scenario shown in Table 11. Drip-irrigated acres also increased to 56,570 as a result of Scenario 2 from

53,949 in the base scenario. The dryland acreage decreased from 39,837 acres to 36,184 acres as Scenario 2 was implemented.

The gross income of Scenario 2 was $788.2 million for the base amount of water available, which was $4.6 million less than the gross income of the base scenario (Table 11). The net income of the region with 900,000 acre-feet of water available in Scenario 2 was $342 million which was smaller than the $344 million of the base scenario (Table 11). As water availability decreased, the corresponding gross income of Scenario 2 was greater than the gross income of reduced water availability in the base scenario. The gross income increased from $716 million in the base scenario to $718 million in Scenario 2 with a reduced availability of water while the net income decreased to $316 million in Scenario 2 from $318 million dollars when compared with the base drip irrigation scenario.

Scenario 3 - 30% yield increase, 20% water savings

Scenario 3 represents an increase in yield of 30 percent for drip-irrigated crops when compared to the respective flood-irrigated crops. Also incorporated into Scenario 3 is a 20 percent water savings over flood irrigation for the drip-irrigated crops. Scenario 3 shows the effects of yields that are greater than that of the published data for most crops. Onions, citrus, and cotton have increased yields over the base scenario, while sugarcane has a lower yield response. The water savings for the field crops is greater for sugarcane, but less for onions and citrus when compared to the base drip irrigation scenario (Table 11).

The results presented in Table 14 define the cropping pattern as Scenario 3 is implemented. The resulting cropping practices for Scenario 3, compared to the base scenario in Table 11, for the base amount of water available indicate that the flood-irrigated acreages decreased from 474,772 to 470,631 acres along with dryland acreages that decreased from 6,435 to 6,194. Drip-irrigated acreages increased as a result of Scenario 3 from 54,459 to 58,835 acres.

Table 14. Cropping Patterns in Acres for Scenario 3, Risk Aversion Level of α=0.00000008[a]

Crop	Reduced Water[b]	Base Water[c]
Bell Pepper, Flood	1,652	3,394
Broccoli, Flood	5,026	10,914
Cabbage, Flood	29,138	29,993
Carrot, Sprinkler	2,500	2,500
Honeydew, Drip	2,476	2,305
Onion, Drip	1,281	1,362
Watermelon, Drip	2,311	1,075
Watermelon, Flood	20,213	21,619
Corn, Flood	0	16,864
Cotton, Drip	17,362	19,106
Cotton, Flood	90,876	124,698
Cotton, Dryland	41,761	6,194
Sorghum, Flood	202,744	241,136
Sorghum, Dryland	0	0
Sugarcane, Drip	9,294	7,987
Sugarcane, Flood	20,707	22,013
Orange, Drip	8,500	8,500
Grapefruit, Drip	18,500	18,500
Flood	370,356	470,631
Drip	59,724	58,835
Dryland	41,761	6,194
Total	471,841	535,660
Available Water at Reservoir	650,000	900,000
Available Water to Producers	485,500	672,200
Water Applied	485,500	645,000
Unused Water	0	27,200
Gross Income (Million Dollars)	721	800.5
Net Income (Million Dollars)	322.1	349.5

[a]Scenario 3 is assuming 30% yield increase and 20% water savings for drip irrigation compared to flood irrigation.
[b] 650,000 acre-feet of water available at reservoir.
[c] 900,000 acre-feet of water available at reservoir.

As available water was restricted, comparing the base drip irrigation results to Scenario 3, flood-irrigated crop acreages decreased from 378,055 to 370,356 acres. Drip-irrigated acreages increased from 53,949 to 59,724, while dryland crop acreages increased as well from 39,837 to 41,761 acres as a result of the effects of Scenario 3 compared to the base drip irrigation scenario.

Due to the 30 percent increase in yield, the gross and net incomes increased for both levels of water when compared to the base drip irrigation scenario. With the base level of water of 900,000 acre-feet available, the gross income increased from $793 million in the base scenario to $801 million in Scenario 3. The net income increased from $344 million in the base scenario to $350 million in Scenario 3. When the amount of water available was constrained to 650,000 acre-feet, the gross income increased from $716 million to $721 million in Scenario 3. The net income increased as well from $318 million to $322 million.

Scenario 4 - Base yield, no water savings

Scenario 4 represents the yield from the base drip irrigation scenario with no water savings realized as drip irrigation is adopted. The results shown in Table 15 illustrate the cropping pattern associated with Scenario 4. As a result of no water savings realized when drip irrigation is adopted, the amount of acres utilizing drip irrigation decreased from the base drip irrigation scenario of 54,459 to 52,520 in Scenario 4 when 900,000 acre-feet of water are available. The flood-irrigated acreages increased to 475,745 from 474,772, while dryland acreages also increased from 6,435 to 7,400 as Scenario 4 was implemented with the base amount of water available, 900,000 acre-feet.

Table 15. Cropping Patterns in Acres for Scenario 4, Risk Aversion Level of α=0.00000008[a]

Crop	Reduced Water[a]	Base Water[b]
Bell Pepper, Flood	1,593	3,399
Broccoli, Flood	4,885	10,940
Cabbage, Flood	29,186	29,987
Carrot, Sprinkler	2,500	2,500
Honeydew, Drip	2,480	2,305
Onion, Drip	1,257	1,426
Watermelon, Drip	2,275	1,081
Watermelon, Flood	20,246	21,614
Corn, Flood	0	16,991
Cotton, Drip	1,245	12,947
Cotton, Flood	105,893	129,652
Cotton, Dryland	42,861	7,400
Sorghum, Flood	202,920	240,923
Sorghum, Dryland	0	0
Sugarcane, Drip	1,654	7,761
Sugarcane, Flood	28,346	22,239
Orange, Drip	8,500	8,500
Grapefruit, Drip	18,500	18,500
Flood	393,069	475,745
Drip	35,911	52,520
Dryland	42,861	7,400
Total	471,841	535,665
Available Water at Reservoir	650,000	900,000
Available Water to Producers	485,500	672,200
Water Applied	485,500	663,100
Unused Water	0	9,100
Gross Income ($Million)	702.6	792.3
Net Income ($Million)	313	342.6

[a]Scenario 4 is assuming the base yield increase and no water savings for drip irrigation compared to flood irrigation.
[b] 650,000 acre-feet of water available at reservoir.
[c] 900,000 acre-feet of water available at reservoir.

As the amount of water available to producers for irrigation purposes decreased, the irrigation practices changed in a similar manner to that associated with the base amount of water available in Scenario 4. Flood irrigation acreage increased from 378,055 in the base scenario (Table 11) to 393,069 acres in Scenario 4. Dryland acreages also increased in Scenario 4 from 39,837 acres in the base scenario to 42,861 acres. Drip-irrigated acres decreased from 53,949 acres to 35,911 acres when compared to the base drip irrigation scenario. This suggests water savings attributable to drip irrigation is important to gain adoption.

As a result of no water savings realized in Scenario 4, the gross income of agriculture for the base amount of water available decreased slightly from $793 million in the base scenario to $792 million. The net income decreased as well from $344 million to $343 million. With a reduced amount of water available for irrigation, the gross income for Scenario 4 decreased to $703 million while the net income decreased to $313 million compared to the base drip irrigation scenario (Table 11).

Scenario 5 - Base yield, water savings on onion 20%, base for everything else

In the event that drip-irrigated onions do not use 53% less water than flood-irrigated onions, Scenario 5 was created. Scenario 5 incorporates the yield responses to drip irrigation found in the base drip irrigation scenario for each crop as well as the water savings for each crop except onions. Onions are defined to have a 20 percent savings in the amount of water applied with drip irrigation as compared to flood-irrigated onions.

The results shown in Table 16 define the cropping pattern for Scenario 5. The effects of Scenario 5 are small due to the only aspect that is changing from the base scenario is the water savings on the onions. With the base amount of water available, flood-irrigated acres increase by 10 acres to 474,782 compared to the base scenario, while dryland acreages decrease from 6,435 to 6,376. Drip-irrigated acres also increase to 54,508 from 54,459 acres compared to the base solution (Table 11).

As water is constrained in the model, flood-irrigated acres decrease while drip-irrigated and dryland acreages increase. Flood-irrigated acreages decrease from 378,055 acres in the base scenario to 377,247 in Scenario 5. Both drip-irrigated and dryland acreages increase in Scenario 5 compared to the base drip irrigation solution. Drip-irrigated acres increase to 54,140 from 53,949 acres in the base scenario, and dryland acres increase to 40,454 from 39,837 acres in the base scenario.

Due to the only difference between the base scenario and Scenario 5 being the water use of onions, the gross and net incomes decrease due to an increase in irrigation cost for drip-irrigated onions. With 900,000 acre-feet of water available for irrigation, the gross income decreased only minimally from $792.8 million in the base scenario to $792.6 million. The net income decrease was also minimal. As water was constrained, the income differences between the base scenario and Scenario 5 became somewhat larger. The gross income decreased from $716 million in the base scenario to $714 million in Scenario 5. The net income decreased to $317 million in Scenario 5 from $318 million in the base scenario.

Table 16. Cropping Patterns in acres for Scenario 5, Risk Aversion Level of α=0.00000008[a]

Crop	Reduced Water[b]	Base Water[c]
Bell Pepper, Flood	1,613	3,377
Broccoli, Flood	5,029	10,814
Cabbage, Flood	29,251	29,997
Carrot, Sprinkler	2,500	2,500
Honeydew, Drip	2,482	2,304
Onion, Drip	1,352	1,446
Watermelon, Drip	2,371	1,060
Watermelon, Flood	20,147	21,635
Corn, Flood	0	16,465
Cotton, Drip	11,500	14,025
Cotton, Flood	98,046	129,599
Cotton, Dryland	40,454	6,376
Sorghum, Flood	202,596	241,568
Sorghum, Dryland	0	0
Sugarcane, Drip	9,435	8,673
Sugarcane, Flood	20,565	21,327
Orange, Drip	8,500	8,500
Grapefruit, Drip	18,500	18,500
Flood	377,247	474,782
Drip	54,140	54,508
Dryland	40,454	6,376
Total	471,841	535,666
Available Water at Reservoir	650,000	900,000
Available Water to Producers	485,500	672,200
Water Applied	485,500	642,300
Unused Water	0	24,500
Gross Income ($Million)	714.4	792.6
Net Income ($Million)	316.9	343.4

[a]Scenario 5 is assuming the base yield increase and base water savings for drip irrigation, with only a 20% water savings for onions compared to flood irrigation.
[b] 650,000 acre-feet of water available at reservoir.
[c] 900,000 acre-feet of water available at reservoir.

Comparison Across Scenarios

The discussion of implications of each of the scenarios was compared with the base drip irrigation solution. This section expands this to a comparison across scenarios for the base water available and reduced water available.

Base water available

Shown in Table 17 are the cropping patterns for 900,000 acre-feet water available in the region for the current cropping pattern as well as the base drip irrigation scenario and sensitivity analyses. As drip irrigation is considered as an option for producers, the agriculture model application suggests an incentive to adopt. The acreages of the other crops in the model that did not have a drip-irrigated counterpart remained relatively stable across scenarios. In each scenario, other than that of the current cropping pattern, grapefruit and oranges utilized drip irrigation instead of the traditional flood for the total amount of acres in orchards.

Table 17. Cropping Patterns in acres for 900,000 Acre Feet of Water Available, Risk Aversion Level of α=0.00000008

Crop	Current[a]	Base[b]	Scenario 1[c]	Scenario 2[d]	Scenario 3[e]	Scenario 4[f]	Scenario 5[g]
Bell Pepper, Flood	3,495	3,377	3,445	3,448	3,394	3,399	3,377
Broccoli, Flood	11,713	10,814	11,603	11,592	10,914	10,940	10,814
Cabbage, Flood	29,779	29,996	29,770	29,766	29,993	29,987	29,997
Carrot, Sprinkler	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Honeydew, Drip	2,321	2,304	2,339	2,338	2,305	2,305	2,304
Onion, Drip	0	1,467	1,345	1,349	1,362	1,426	1,446
Watermelon, Drip	1,329	1,061	1,370	1,360	1,075	1,081	1,060
Watermelon, Flood	21,350	21,635	21,291	21,302	21,619	21,614	21,635
Corn, Flood	20,701	16,465	20,175	20,178	16,864	16,991	16,465
Cotton, Drip	0	13,956	10,673	11,137	19,106	12,947	14,025
Cotton, Flood	135,677	129,609	129,825	129,822	124,698	129,652	129,599
Cotton, Dryland	14,322	6,435	9,502	9,041	6,194	7,400	6,376
Sorghum, Flood	237,976	241,547	237,327	237,332	241,136	240,923	241,568
Sorghum, Dryland	0	0	0	0	0	0	0
Sugarcane, Drip	0	8,671	0	161	7,987	7,761	8,673
Sugarcane, Flood	30,000	21,329	29,999	29,840	22,013	22,239	21,327
Orange, Drip	0	8,500	8,500	8,500	8,500	8,500	8,500
Orange, Flood	8,500	0	0	0	0	0	0
Grapefruit, Drip	0	18,500	18,500	18,500	18,500	18,500	18,500
Grapefruit, Flood	18,500	0	0	0	0	0	0
Flood	517,691	474,772	483,435	483,280	470,631	475,745	474,782
Drip	3,650	54,459	42,727	43,345	58,835	52,520	54,508
Dryland	14,323	6,435	9,502	9,041	6,194	7,400	6,376
Total	535,664	535,616	535,664	535,666	535,660	535,665	535,666
Gross Income ($Million)	758.5	792.8	788	788.2	800.5	792.3	792.6
Net Income ($Million)	328.5	343.6	341.8	342	349.5	342.6	343.4

[a]Drip irrigation only in place for crops currently using it.
[b]Base yield responses and water savings with drip irrigation.
[c]20% yield increase and 20% water savings for drip irrigation.
[d]20% yield increase and 20% water savings for drip irrigation.
[e]20% yield increase and 20% water savings for drip irrigation.
[f]20% yield increase and 20% water savings for drip irrigation.
[g] Same as base scenario, but with 20% water savings for onions.

Onions, which were not present in the current cropping pattern, were planted in the base drip irrigation scenario as well as the other scenarios of the sensitivity analysis. Scenario 1 and 2, compared to the base case required the onions to use more water; hence less drip-irrigated onions were planted. As the yield was increased in Scenario 3, the acreages of drip-irrigated onions decreased by about 100 acres from the base scenario. When the base yield response was retained, but the water savings decreased in Scenario 4 and 5 compared to the base drip irrigation solution, the amount of onions planted also decreased.

Drip-irrigated cotton is shown in the base drip irrigation scenario receiving about half its acres from cotton that is currently flood-irrigated and the other half from dryland cotton when compared to the current situation. As the water savings for drip-irrigated cotton remain the same in Scenario 1 and increase in Scenario 2 when compared to the base scenario, the amount that is planted decreases in both Scenario 1 and 2. However, when the yield response to drip irrigation increases in Scenario 3 the amount planted increases to 19,106 acres as compared to 13,956 acres in the base, scenario. With no water savings realized due to the adoption of drip irrigation in Scenario 4, about 1,000 fewer acres are planted. Results of Scenario 5 (change only onion water usage), indicate the amount of drip-irrigated cotton will increase slightly to 14,025 acres.

Flood-irrigated sugarcane acreage is also replaced with drip-irrigated sugarcane as drip irrigation is introduced. As the increased yield response of sugarcane is decreased from

39% to 20% in Scenario 2 and 3, the acres of drip-irrigated sugarcane decrease substantially to 0 and 161 acres, respectively. In Scenario 3, sugarcane still has a lower yield response to drip irrigation than in the base scenario and as a result, only 7,987 acres are drip-irrigated. Scenario 4 (no water savings are realized) drip-irrigated acreage declines from 8,671 to 7,761. The acres of drip-irrigated sugarcane planted in Scenario 5 remain about the same, only increasing two acres when compared with the base scenario.

In reviewing the overall implication, with the drip irrigation option, acres drip-irrigated increased from the current 3,650 to between 42,727 and 58,835. Gross and net agricultural income naturally increased with a drip irrigation option compared to the current situation. The increase in gross income, compared to the current income of $759 million, ranged from $788 to $801 million. Similarly, net income increased from $329 million to between $342 and $350 million.

Reduced water available

Restricted water availability suggests an incentive to adopt drip irrigation with the expected lower water application compared to furrow irrigation. The results for 650,000 acre-feet are shown in Table 18. The acreages of the crops that are present in the current cropping pattern that do not have the option of being drip-irrigated remain at the same level as each scenario is implemented in the model. As drip irrigation is introduced into the model, the acreages of citrus immediately shift from flood irrigation to drip irrigation and remain in drip irrigation across all of the scenarios.

Flood-irrigated onions were not present in the current cropping pattern, but appear in the base scenario utilizing drip irrigation with 1,445 acres planted. Across the scenarios, the acreages of drip-irrigated onions decrease as a result of decreased water savings. When there is less water saved in Scenario 1 and 2, the acreages decrease to 1,287 and 1,335, respectively. The acreages of drip-irrigated onions also decrease in Scenario 3 when the yield response increases to 30% and the water savings is only 20%. Implementing Scenario 4 and 5 also resulted in fewer acres of drip-irrigated onions planted when compared with the base scenario.

Drip-irrigated cotton acres in the base drip irrigation scenario came from flood irrigation. Dryland cotton also increased in Scenario 3 and 4. In the base scenario, 11,280 acres of drip-irrigated cotton are present in the cropping pattern. As Scenario 1 was applied to the model, the amount of drip-irrigated cotton decreased to 8,868 acres. When greater water savings were realized, which was the case in Scenario 2, the drip-irrigated acreages increased to 14,365. The greatest change observed with drip-irrigated cotton was when Scenario 3 was implemented. Scenario 3 represented a 30 percent increase in yield while maintaining 20 percent water savings. The amount of drip-irrigated cotton planted increased to 17,362 acres as a result. When no water savings were realized in

Scenario 4, the amount of drip-irrigated cotton decreased substantially to 1,245 acres. Scenario 5 resulted in roughly the same amount of cotton planted as in the base scenario.

Drip-irrigated sugarcane was also planted ranging from 1,654 to 9,435 acres. There was a tradeoff between flood and drip-irrigated sugarcane. As more drip-irrigated sugarcane was present in the cropping pattern, less flood-irrigated sugarcane was planted. As a result of having a lower yield response and a greater amount of water savings in Scenario 1, the planted acreage of drip-irrigated sugarcane present in the cropping pattern decreased to 4,351 from 9,417 in the base scenario. In Scenario 4, when the base yield response was present and there was also no water saved, the acreage also declined to 1,654. The acreages in the cropping patterns for Scenarios 2, 3, and 5 were similar to those present in the base scenario.

With drip irrigation allowed as an option of irrigation technology in the agricultural model, drip-irrigated acres increased from the current 4,486 to between 35,911 and 59,724. Gross and net agricultural income also increased as the option to utilize drip irrigation was implemented when compared to the current situation. The increase in gross income compared to the current income of $679 million, ranged from $703 to $721 million. Net income also increased from $301 million using current irrigation methods to between $313 and $322 million.

Table 18. Cropping Patterns in Acres for 650,000 Acre Feet of Water Available, Risk Aversion Level of α=0.00000008

Crop	Current[a]	Base[b]	Scenario 1[c]	Scenario 2[d]	Scenario 3[e]	Scenario 4[f]	Scenario 5[g]
Bell Pepper, Flood	1,714	1,635	1,691	1,781	1,652	1,593	1,613
Broccoli, Flood	5,193	5,086	5,202	5,504	5,026	4,885	5,029
Cabbage, Flood	29,386	29,287	29,395	29,564	29,138	29,186	29,251
Carrot, Sprinkler	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Honeydew, Drip	2,457	2,478	2,460	2,448	2,476	2,480	2,482
Onion, Drip	0	1,445	1,287	1,335	1,281	1,257	1,352
Watermelon, Drip	2,029	2,329	2,145	2,072	2,311	2,275	2,371
Watermelon, Flood	20,514	20,193	20,395	20,481	20,213	20,246	20,147
Corn, Flood	0	0	0	0	0	0	0
Cotton, Drip	0	11,280	8,868	14,365	17,362	1,245	11,500
Cotton, Flood	110,245	98,882	101,524	99,451	90,876	105,893	98,046
Cotton, Dryland	39,755	39,837	39,608	36,184	41,761	42,861	40,454
Sorghum, Flood	203,548	202,389	202,266	201,657	202,744	202,920	202,596
Sorghum, Dryland	0	0	0	0	0	0	0
Sugarcane, Drip	0	9,417	4,351	9,350	9,294	1,654	9,435
Sugarcane, Flood	29,999	20,583	25,649	20,650	20,707	28,346	20,565
Orange, Drip	0	8,500	8,500	8,500	8,500	8,500	8,500
Orange, Flood	8,500	0	0	0	0	0	0
Grapefruit, Drip	0	18,500	18,500	18,500	18,500	18,500	18,500
Grapefruit, Flood	18,500	0	0	0	0	0	0
Flood	427,599	378,055	386,122	379,088	370,356	393,069	377,247
Drip	4,486	53,949	46,111	56,570	59,724	35,911	54,140
Dryland	39,755	39,837	39,608	36,184	41,761	42,861	40,454
Total	471,840	471,841	471,841	471,842	471,841	471,841	471,841
Gross Income ($Million)	678.9	716.1	709.4	718.2	721	702.6	714.4
Net Income ($Million)	300.9	317.6	314	316.4	322.1	313	316.9

[a]Drip irrigation only in place for crops currently using it.
[b]Base yield responses and water savings with drip irrigation.
[c]20% yield increase and 20% water savings for drip irrigation.
[d]20% yield increase and 20% water savings for drip irrigation.
[e]20% yield increase and 20% water savings for drip irrigation.
[f]20% yield increase and 20% water savings for drip irrigation.
[g] Same as base scenario, but with 20% water savings for onions.

Shadow Price of Water

The shadow price of a variable present in a linear programming model represents the "value of an additional unit of a limiting resource" (Harsh, Connor, and Schwab 1981). In the case of this model, the variable of interest is water. The shadow price of the water can be interpreted as the additional value added to the objective function, or net income, as an additional unit of water is available due to a relaxation of the constraint in the model.

The shadow price of water is a product of the application of the agricultural model. Shown in Table 19 are the amounts of water used and the resulting shadow price for water at each risk level for the base level of water available. For a risk level of α=0.00000000 and α=0.00000005, all of the available water was used to produce crops. Since all of the water was used, there was a shadow price, or the next unit of available water would increase the net revenue for the model application. The shadow price for α=0.00000000 was $928.10 per acre-foot, while it was only $41 per acre-foot for α=0.00000005. As the risk aversion levels increased to α=0.00000008 and α=0.00000010, the resulting shadow price of the water was zero. A shadow price of zero means that the water constraint in the model is not binding, or all of the water is not consumed. The amount of water used decreased from 672,200 acre-feet where α=0.00000000 and α=0.00000005 to 640,800 acre-feet where α=0.00000008 and 616,700 acre-feet where α=0.00000010.

Table 19. Amount of Water Used and Resulting Shadow Price across all Levels of Risk Aversion for 900,000 Acre-Feet Available at the Reservoir[a]

	Risk Aversion Levels[b]			
	0.00000000	0.00000005	0.00000008	0.00000010
Shadow Price[c]	$928.10	$41.00	$0	$0
Acre-Feet Used[d]	672.2	672.2	640.8	616.7
Acre-Feet Unused[d]	0	0	31.4	55.5
Transport Losses[d]	227.8	227.8	227.8	227.8

[a]For a total of 900,000 acre-feet at the reservoir, only 672,200 acre-feet are delivered to farms due to transportation losses.
[b]Risk aversion levels increase from left to right.
[d]The shadow price is an estimate of how much one additional unit of water would increase the objective function or net income.
[d]Thousands of acre-feet.

Shown in Table 20 are the amounts of water used and the resulting shadow price for varying levels of water available where α=0.00000008. As the amount of water is constrained in the model, the total amount of water available, 485,500 acre-feet, is used, resulting in a shadow price of $157.60 per acre-foot. However, as water is increased, the amount of water used by model application remains the same, leaving unused water and resulting in a zero shadow price.

Table 20. Amount of Water Used and Resulting Shadow Price for Varying Levels of Water Available at the Reservoir, Risk Aversion Level of α=0.00000008

	Reduced Water[a]	Base[b]	Additional Water[c]
Shadow Price[d]	$157.60	$0	$0
Acre-Feet Used[e]	485.5	640.8	640.8
Acre-Feet Unused[e]	0	31.4	31.4
Transport Losses[e]	164.5	227.8	933.6

[a]650,000 acre-feet available at the reservoir.
[b]900,000 acre-feet available at the reservoir.
[c]1,250,000 acre-feet available at the reservoir.
[d]The shadow price is an estimate of how much one additional unit of water would increase the objective function or net income.
[e]Thousands of acre-feet.

The amount of water used and the resulting shadow price for each scenario with 900,000 acre-feet of water available where α=0.00000008 is shown in Table 21. Since there is unused water across all scenarios, there is a zero shadow price in all cases. The amount of water used in each of the scenarios is greater than that of the base drip irritation scenario, with Scenario 4 using the most water. This is a result of no water savings being realized in Scenario 4.

Table 21. Amount of Water Used and Resulting Shadow Price by Scenario for 900,000 Acre-Feet of Water Available, Risk Aversion Level of α=0.00000008

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Shadow Price[a]	$0	$0	$0	$0	$0
Acre-Feet Used[b]	652.9	647.7	645	663.1	642.3
Acre-Feet Unused[b]	19.3	24.5	27.2	9.1	29.9
Transport Losses[b]	227.8	227.8	227.8	227.8	227.8

[a]The shadow price is an estimate of how much one additional unit of water would increase the objective function or net income above specified costs.
[b]Thousands of acre-feet.

The estimated amount of water used and resulting shadow price for each scenario is shown in Table 22 for an amount of available water of 650,000 acre-feet where α=0.00000008. With a reduced amount of water available, the resulting cropping patterns for each scenario use the full amount of water. Since the full amount of water is used, it is logical that the availability of more water would increase the net income above specified costs. The resulting shadow prices range from $140.5 in Scenario 2 where water savings with drip irrigation are the greatest of the scenarios to $171.70 in Scenario 4 where there are no water savings. That is, so long as an additional unit of water could be obtained for less than the respective shadow price values, the objective function's returns above specified costs would increase.

Table 22. Amount of Water Used and Resulting Shadow Price by Scenario for 650,000 Acre-Feet of Water Available, Risk Aversion Level of α=0.00000008

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Shadow Price[a]	$156.50	$140.50	$166.60	$171.70	$160.50
Acre-Feet Used[b]	485.5	485.5	485.5	485.5	485.5
Acre-Feet Unused[b]	0	0	0	0	0
Transport Losses[b]	164.5	164.5	164.5	164.5	164.5

[a]The shadow price is an estimate of how much one additional unit of water would increase the objective function or net income.
[b]Thousands of acre-feet

Impact of Water Delivery Costs

The price of the irrigation water was varied to test the sensitivity of the model. This provides insight on the implications of increased water prices on the amount of drip irrigation adopted and the net income of the region. The water prices were varied for both the base amount of water available of 900,000 acre-feet, and a reduced 650,000 acre-feet level of water available. Recall these are water amounts at the reservoir and suffer losses before reaching the farm. The prices of water delivery per acre-foot used in this analysis were $60, $100, and $500, compared with the current price of $20 per acre-foot.

Base water available

The expected cropping pattern effects of the pricing structure of water are presented in Appendix B. Presented in Table 23 are the effects of the varying delivery price on irrigation type and net income. As the price of the water increases, the flood-irrigated acreages decrease from 474,772 at the base price of $20 per acre-foot to between 467,146 acres at a price of $60 per acre-foot and 216,830 acres at a price of $500 per acre-foot. Dryland acreages increase from 6,435 to 129,131 as the price increases from $20 to $500 per acre-foot. Drip-irrigated acreages increase from 54,459 to 58,215 as the price increases from $20 to $100 per acre-foot. As the price of water increases to $500 per acre-foot, the drip-irrigated acreages decline to 40,030. The decline in drip irrigation as the cost of delivery rises to $500 is due to drip irrigation not being economical at such high delivery costs even though it is technologically preferred.

Flood-irrigated corn acreages declined substantially as the price of water increased eventually reaching 0 at a price level of $500 an acre foot. Drip-irrigated acreages of cotton increased as the cost of delivery rose from $20 to $100, but as the cost increased to $500 there were no acres of drip-irrigated cotton present in the cropping pattern. The amount of flood-irrigated cotton at a cost of $500 was less than half the acres at a cost of $20, while the amount of dryland cotton increased from 6,435 acres at a cost of $20 to 89,878 acres when the price of water is $500 per acre-foot. Flood-irrigated sorghum acreages increased as the cost rose from $20 to $100, but as the cost increased to $500 the total irrigated acres decreased. To compensate for the decrease in acreages of flood-irrigated sorghum, dryland acres appear in the cropping pattern at a price of $500. As the cost of water delivery increases from $20 to $100, the amount of drip-irrigated sugarcane steadily increases. However, when the cost of delivery increases to $500 per acre-foot, the amount of drip-irrigated sugarcane declines slightly. The amount of flood-irrigated sugarcane acres does the exact opposite of the drip-irrigated sugarcane and decreases as the cost of delivery increases to $100 per acre foot, but as the cost reaches $500 the amount of flood-irrigated sugarcane increases due to the constraints present in the model.

An increase in the cost of water certainly impacts the net income of the region. As the cost of water increases, the net income above specified costs of the region decreases as would be expected, all else equal. The net income only decreases by 1.2 million dollars as the cost rises from $20 to $60, which is small compared to the change in income as the cost continues to increase. As the cost of water increases to $100, the net income decreases to 291.1 million dollars. The net income decreases to 97.6 million dollars when the cost of water is at $500 per acre-foot.

Table 23. Acres per Irrigation Type and Net Income for Alternative Water Delivery Prices, 900,000 Acre-Feet of Water Available, Risk Aversion Level of α=0.00000008

Price per Acre-foot	\$20	\$60	\$100	\$500
Flood	474,772	467,146	446,117	216,830
Drip	54,459	54,568	58,215	40,030
Dryland	6,435	13,951	21,706	129,131
Acre-Feet Used[a]	640.8	611.1	560.1	293.1
Acre-Feet Unused[a]	31.4	61.1	112.1	379.1
Transport Losses[a]	227.8	227.8	227.8	227.8
Net Income[b]	317.6	316.4	291.1	97.6

[a]Thousands of Acre-Feet.
[b]Millions of Dollars.

Reduced water available

Cropping patterns were similar for a reduced amount of water available of 650,000 acre-feet. As the price of water was increased to \$500 per acre-foot, the resulting cropping pattern for the reduced level of water was the same as the cropping pattern for the base level of water. Flood-irrigated acreages decreased from 378,055 to 216,830 as the cost of water increased from \$20 to \$500 per acre-foot. Drip-irrigated acreages increased from 53,949 to 55,235 as the cost increased from \$20 to \$100 per acre-foot of water, but decreased to 40,030 acres as the cost of water increased to \$500 per acre-foot. Dryland acres decreased slightly from 39,837 to 39,669 as the price increased from \$20 to \$60 per acre-foot. However, as the cost of water increased to \$100 per acre-foot, the dryland acreage increased to 40,389. The dryland acreage further increased to 129,131 as the cost of water increased to \$500 per acre-foot.

The detailed cropping pattern effects of the pricing change of the water are available in Appendix B. Table 24 is a report of the effect of the varying costs on irrigation type and net income above specified costs. Fewer drip-irrigated onions were planted as the cost of water increased, while more acres of drip-irrigated cotton were planted. Flood-irrigated acres of cotton decreased, while dryland cotton acreages increased as the cost of water increased. The amount of flood-irrigated sorghum decreased as cost increased to $500 per acre-foot. With the cost of water being $500, dryland sorghum appeared in the cropping pattern for the first time. As the cost of water increased, the amount of drip-irrigated sugarcane increased, while the amount of flood-irrigated sugarcane decreased.

The net income above specified costs of the region was affected more negatively as the cost of water increased with a constrained amount of water available. The net income of the region decreased from $343.6 million at a base price of $20 per acre-foot to $300 million when the cost of water was increased to $60 per acre-foot. As the cost increased to $100 the net income decreased to $281.9 million. The net income fell to $97.6 million when the cost of water increased to $500 per acre-foot.

Table 24. Acres per Irrigation Type and Net Income for Alternative Water Delivery Prices, 650,000 Acre-Feet of Water Available, Risk Aversion Level of α=0.00000008

Price per Acre-foot	$20	$60	$100	$500
Flood	378,055	377,215	376,218	216,830
Drip	53,949	54,957	55,235	40,030
Dryland	39,837	39,669	40,389	129,131
Acre-Feet Used[a]	485.5	485.5	485.5	293.1
Acre-Feet Unused[a]	0	0	0	192.4
Transport Losses[a]	164.5	164.5	164.5	164.5
Net Income[b]	343.6	300	281.9	97.6

[a]Thousands of Acre-Feet.
[b]Millions of Dollars.

LIMITATIONS

To aid in the interpretation of results, a clear understanding of the limitations of this research is useful. The majority of the limitations are related to the regional model and its application to drip irrigation. Assumptions related to water use and yield response to drip irrigation clearly dictate results of the model. In addition, being a maximizing model, it suggests producers will make decisions to maximize annual net returns above specified costs. There are a multitude of factors impacting producers' decisions including risk, weather variability, finances, tradition, and internal goals.

It is assumed in model application that producers in the region are able to plant all crops that are grown in the area. The LRGV has a diverse set of crops that can be cultivated due to the location and climate of the area. Due to the diverse crops present in the region, there is a certain level of knowledge as well as specialized farm equipment that producers must possess to grow the crops available. By not having the necessary skill sets, the producers may experience differing returns than those that are reflected in the data analyzed.

The length of life assumed for the capital assets needed to invest in drip irrigation may be understated or overstated, depending on the producers that are maintaining the equipment. Since producers have differing opinions regarding the maintenance of equipment, the annual costs could be altered. Altering the maintenance costs could ultimately have an effect on the economic feasibility of the investment.

It is also assumed that producers will purchase a separate drip trailer system for each crop that they are drip irrigating. If the producers will be irrigating more than one crop with drip irrigation, they may be able to use the drip trailer for additional crops if the irrigation schedules are staggered. If producers are able to utilize the drip trailer for more than one crop and for more than one 40 acre field, the costs that will be incurred upon adopting drip will decrease, making it more attractive to invest in drip irrigation.

The research also does not take into consideration possible quality differences in the crops that may occur as drip irrigation is adopted. With quality differences present in the drip-irrigated crops, the price received when the crops are sold may vary, which could change the price received for those crops. Along these same lines, the opportunity to use drip irrigation to modify the maturity of a crop to meet unique marketing windows was not considered.

The research also assumes that as drip irrigation is adopted in place of flood irrigation, the only variable costs that are altered are changes in harvesting/processing costs and related to irrigation, such as irrigation supplies, irrigation labor, and the repair and maintenance of the drip system. Once drip irrigation is implemented, however, the amount of fertilizer or chemicals that are applied to the crop may vary as well as some field operations, affecting the returns per acre; consideration of these possible cost changes is not included in this research.

A major issue related to the research is the assumption that with limited water in one year, drip irrigation will be adopted. With adequate water, the adoption of drip is very limited. This suggests that expectations and the outlook for water availability in the long run are very important in decisions for farmers. It is unlikely farmers will adopt drip irrigation if the outlook is for only a temporary shortage of water.

It is also assumed that producers in the area all possess the same attitude of risk aversion. Producers' outlooks on risk will vary, which ultimately impacts their decisions on the types of crops that are planted and the management practices that are implemented such as the type of irrigation technology that is utilized.

There is uncertainty related to the outlook for the demand of agricultural commodities as well as the structure of the legislative farm programs. The model assumes that the demand for these commodities remains constant over time, which could impact the results of which crops are present in the regional cropping pattern. Farm programs which serve as a revenue support were not included in the model. The inclusion of these farm programs could result in a differing cropping pattern for the region due to the support provided for certain crops.

The Texas Lower Rio Grande Valley is experiencing exceptional population growth, which ultimately results in the conversion of agricultural land to urban land. As the population increases, there is also an increased demand for water in the region. The model that was applied for this study did not consider the changing land resources, or increased demand for water. As agricultural land is converted for urban use, the cropping pattern that would result for the area may produce different results due to the reduced land area. With an increase in the demand for water due to the increasing population, the price of water may increase, leading to differing cropping patterns that are present in the results due to the higher water price and reduced availability of land for production.

Along with limitations to the research, there is also a need for further study on the subject of drip irrigation in the valley. For a more robust economic analysis to be completed on the feasibility of drip irrigation, research needs to be completed that directly compares flood-irrigated crops and drip-irrigated crops. This would allow for actual yield, water use, and cost data that could then be incorporated into an economic feasibility study.

SUMMARY AND CONCLUSIONS

This thesis is an economic analysis of drip irrigation for alternative crops that currently are primarily flood-irrigated in the Texas Lower Rio Grande Valley. The economic feasibility of drip irrigation is determined using net present value analysis and a regional agricultural model. The net present value method allows for a partial budgeting analysis of the feasibility of the technology by crop on a per acre basis while only considering the current prices and costs. The agricultural model application is a more aggregate analysis of the entire region considering risk, available water, historical prices and yields, and soil type across crops and irrigation technologies.

The capital budgeting analysis suggests that drip irrigation is only economically feasible for citrus crops based on the yield levels, water use, and prices used in this study. The feasibility is determined by a comparison of the RASC and NPV of flood and drip irrigation. If the RASC and NPV are greater for drip irrigation, it is determined to be economically feasible. As mentioned above, citrus was the only crop for which it was economically feasible to adopt drip irrigation. Drip-irrigated grapefruit had an NPV that was $3,533.22 greater than that of the flood-irrigated grapefruit per acre, while oranges had a positive difference of $1,746.63 between drip irrigation and flood irrigation per acre. The NPVs of the drip-irrigated onions, cotton, and sugarcane were less than the NPV of the flood-irrigated crops. The drip-irrigated onion NPV per acre was $8,036.97 lower than that of the flood-irrigated onions. Cotton and sugarcane had a slightly less negative difference between flood-irrigated and drip-irrigated NPVs. The NPV of drip-irrigated cotton was $256.44 less than the flood-irrigated cotton NPV, while the NPV of drip-irrigated sugarcane was $411.45 less than the NPV of flood-irrigated sugarcane. As a result, onions, cotton, and sugarcane were determined to not be economically feasible due to a lower RASC and NPV with drip irrigation when compared with flood irrigation. In order for these crops to be feasible under the current assumptions, the yields would have to be increased.

A breakeven analysis was performed to determine the yields in which the RASC of the drip-irrigated crops would equal the RASC of the flood-irrigated crops. This provides insight on the ultimate yield response that is needed for drip irrigation to be economically feasible. The breakeven yields per acre that were calculated were 1,394 sacks for onions, 1,056 pounds for cotton, and 74 tons for sugarcane. Cotton and sugarcane would only have to increase from the original yield assumption by 8% and 9% respectively, whereas onions would have to increase 35% over the original assumption. The large difference in the breakeven yield of onions is due to the assumed required replacement of the drip tape each season after the onions are harvested. If producers can spread the drip tape over more years, the breakeven yield will naturally be smaller.

The regional agricultural model was applied to estimate the cropping patterns of the area as a drip irrigation option is introduced with other factors such as risk, water constraints, and acreage constraints. The model was applied for alternative levels of water available of 900,000 acre-feet and 650,000 acre-feet. These levels represent water for agriculture at the reservoir; hence, at the farm gate, water availability is reduced by about 25% to account for evaporation and percolation. As drip irrigation was included for the crops of interest, model application provided insight to crops irrigated by drip. With the base level of water available of 900,000 acre-feet, there were 54,459 acres of drip-irrigated crops present in the area cropping pattern, with 474,772 acres that were flood-irrigated. The resulting net income above specified costs of the area was $344 million. As water was restricted to 650,000 acre-feet, the acreages of those crops irrigated by drip decreased to 53,949 acres, while acres of dryland alternatives increased from 6,435 to 39,837 and flood-irrigated acreages decreased to 378,055. The net income above specified costs of the area also decreased as a result of less water available to $318 million.

A sensitivity analysis was completed using the regional agricultural model, in which scenarios were created that differed by varying the amount of water savings realized and the yield response as drip irrigation was adopted. The scenarios were run with the base level of water available and a reduced level of water available. With the base level of water available in the model, scenarios were run for a lower yield response for most of the crops, the amount of drip present in the solution decreased from 54,459 acres in the base solution to between 42,727 and 43,345 acres, while flood-irrigated acres increased to between 483,280 and 483,435 from 474,772 acres under the base solution. The net income for these scenarios decreased from $344 million to $342 million. When the yield response increased to 30% for all crops, the drip-irrigated acreage increased to 58,835 while flood-irrigated acreages decreased to 470,631. Due to the increase in yield response, the net income above specified costs for the region increased to $350 million. When the yield responses remained the same as the base scenario, but no water savings were realized, the amount of drip acres decreased to 52,520 while flood-irrigated acres increased slightly to 475,745. With no water savings realized, the net income above specified costs decreased by $1million to $343 million. Drip-irrigated acres increased slightly to 54,508 as only the level of water savings on onions was reduced. Flood-irrigated acres only increased by 10 to 474,782 as this scenario was implemented. With this scenario in place, the net income above specified costs of the area declined slightly to $343.4 million.

As the amount of available water was reduced, analyses of the scenarios provided differing results. With reduced yield and water savings, compared to the base case, the amount of drip acres decreased from the base amount of 53,949 to 46,111 while flood-irrigated acres increased to 386,122 from 378,055. Due to a lower yield response and water savings, the net income of the area decreased from $318 million to $314 million. As water savings were increased in the scenarios, more acres of drip irrigation were present in the solution increasing to 56,570; however flood-irrigated acres also increased to 379,088. The net income of the area only declined to $316 million as a result. With an increased yield response with drip irrigation, the drip-irrigated acres increased to 59,724 with flood-irrigated acres decreasing to 370,356. As the yield response to drip irrigation increased, the net income of the region increased to $322 million. When the scenario was implemented that involved no water savings and the same yield response as the base scenario with drip irrigation, the drip-irrigated acres decreased to 35,911 while flood-irrigated acres increased to 393,069 resulting in a decrease of net income to $313 million. As the water savings of drip-irrigated onions was decreased to 20%, the total drip-irrigated acres increased to 54,140, while flood-irrigated acres decreased to 377,247. This scenario resulted in a slight decrease in net income to $317 million.

The model was also used to determine the sensitivity of drip irrigation to the cost of water delivery. The cost sensitivity was applied for both the base amount of water and a reduced amount of water. As the cost of water increased from $20 to $100 with the base amount of water available, the drip-irrigated acreages increased from 54,459 to 58,215. When the cost of water increased to $500 an acre-foot, the number of drip-irrigated acres decreased to 40,030. The acreages of dryland crops increased from 6,435 to 129,131 while flood-irrigated acreages decreased from 474,772 to 216,830 due to cost increases. As a result of an increased cost of water, the net income of the region decreased from $318 million to $98 million. When the amount of water was reduced in the model, the results were similar to the base. The flood-irrigated acres decreased from 378,055 to 216,830 while dryland acres increased from 39,837 to 129,131. The amount of drip-irrigated acres increased from 53,949 to 55,235 as the cost increased from $20 to $100, but as the cost increases to $500 per acre-foot, the drip-irrigated acreages decrease to 40,030.

Given the conclusions, this research suggests a decision to reject the null hypothesis as stated in the "Objectives" section (i.e., "The adoption of drip irrigation in the Lower Rio Grande Valley is not economically feasible."). This decision was made due to the presence of drip irrigation in all of the iterations of the agricultural model, suggesting drip irrigation is economically feasible for at least some enterprises in the region as a whole. When looking at individual crops, however, the null hypothesis would be rejected for the citrus crops, while the null hypothesis would be accepted for onions, cotton, and sugarcane. However, when there is very limited water available, the adoption of drip irrigation becomes more feasible.

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APPENDIX A

MODIFIED CROP ENTERPRISE BUDGETS FOR THE TEXAS LOWER RIO GRANDE VALLEY

				Furrow			Drip	
	Item	Unit	Price	Quantity	Amount	Price	Quantity	Amount
Income	Onions, Yellow	sack	$ 7.00	900	$ 6,300.00	$ 7.00	1080	$ 7,560.00
Total Income					$ 6,300.00			$ 7,560.00
Direct Expenses								
	Fertilizer							
	Fert 10-34-0	cwt	$ 67.92	2	$ 135.84	$ 67.92	2	$ 135.84
	Foligro	qt	$ 37.00	7	$ 259.00	$ 37.00	7	$ 259.00
	UAN (32% N)	cwt	$ 46.00	0.78	$ 35.88	$ 46.00	0.78	$ 35.88
	Fungicide							
	Dithane F-45	qt	$ 3.54	2	$ 7.08	$ 3.54	2	$ 7.08
	Rovral 4f	pt	$ 26.05	3	$ 78.15	$ 26.05	3	$ 78.15
	Ridomil Gold	oz	$ 6.25	8	$ 50.00	$ 6.25	8	$ 50.00
	Bravo Ultrex	qt	$ 16.00	2	$ 32.00	$ 16.00	2	$ 32.00
	Herbicide							
	Prefar 4E	qt	$ 13.44	2.75	$ 36.96	$ 13.44	2.75	$ 36.96
	Goal 2XL	gal	$ 138.43	0.1	$ 13.84	$ 138.43	0.1	$ 13.84
	Trifluralin 4EC	pt	$ 4.29	1	$ 4.29	$ 4.29	1	$ 4.29
	Insecticide/miticide							
	Lorsban 4E	pt	$ 6.28	1.75	$ 10.99	$ 6.28	1.75	$ 10.99
	Diazinon AG500	pt	$ 5.92	1	$ 5.92	$ 5.92	1	$ 5.92
	Karate	oz	$ 3.75	9.6	$ 36.00	$ 3.75	9.6	$ 36.00
	Irrigation Supplies							
	Drip Trailer System							$ 59.21
	Drip Tape	ft						$ 1,377.79
	Other Drip Materials							$ 79.93
	Irrigation Water	ac-ft	$ 20.00	2.8	$ 56.00	$ 20.00	1.3132	$ 26.26
	Seed/Plants							
	Onion Seed	unit	$ 147.00	1.5	$ 220.50	$ 147.00	1.5	$ 220.50
	Custom Hort. Harvest							
	Harvest onions	bag	$ 1.65	900	$ 1,485.00	$ 1.65	1080	$ 1,782.00
	Drying onions	bag	$ 0.33	900	$ 297.00	$ 0.33	1080	$ 356.40
	Pack and Count onions	bag	$ 1.60	900	$ 1,440.00	$ 1.60	1080	$ 1,728.00
	Sale Consign. Onions	bag	$ 0.44	900	$ 396.00	$ 0.44	1080	$ 475.20
	Operator Labor							
	Tractors	hour	$ 7.50	1.527	$ 11.45	$ 7.50	1.527	$ 11.45
	Hand Labor							
	Implements	hour	$ 7.50	0.368	$ 2.76	$ 7.50	0.368	$ 2.76
	Irrigation Labor							
	Labor	hour	$ 7.50	7	$ 52.50	$ 7.50		
	Labor (Irr. Setup)	hour	$ 7.50	0.4	$ 3.00	$ 7.50		
	Drip Labor					$ 7.50	0.2206176	$ 1.65
	Unallocated Labor	hour	$ 7.50	0.1527	$ 1.15	$ 7.50	0.1527	$ 1.15
	Diesel Fuel							
	Tractors	gal	$ 3.10	11.4429	$ 35.47	$ 3.10	11.4429	$ 35.47
	Drip Trailer	gal						$ 33.16
	Repair and Maintenance							
	Implements	acre	$ 5.38	1	$ 5.38	$ 5.38	1	$ 5.38
	Tractors	acre	$ 9.71	1	$ 9.71	$ 9.71	1	$ 9.71
	Drip System	acre						$ 5.52
	Interest on Operating Capital	acre	$ 86.03	1	$ 86.03	$ 86.03	1	$ 86.03
Total Direct Expenses					$ 4,807.90			$ 7,003.53
Returns Above Specified Expenses					$ 1,492.10			$ 556.47

Source: Texas AgriLife Extension Service (2012a) with own modifications

Exhibit A1. Crop Enterprise Budget for Furrow and Drip Irrigated Yellow Onions, 2012

			Furrow			Drip	
Item	Unit	Price	Quantity	Amount	Price	Quantity	Amount
Income							
Cotton Lint	lb	$ 0.81	825	$ 668.25	$ 0.81	990	$ 801.90
Cotton Seed	ton	$ 215.00	0.736	$ 158.24	$ 215.00	0.8415	$ 180.92
Total Income				$ 826.49			$ 982.82
Direct Expenses							
Custom Spray							
App by Air (3gal)	appl	$ 5.75	3	$ 17.25	$ 5.75	3	$ 17.25
Harvest Aid							
Dropp 50 WP	lb	$ 55.45	0.2	$ 11.09	$ 55.45	0.2	$ 11.09
Processing							
Gin	lb	$ 0.12	825	$ 99.00	$ 0.12	990	$ 118.80
Fertilizer							
UAN (32% N)	cwt	$ 46.00	2.5	$ 115.00	$ 46.00	2.5	$ 115.00
Herbicide							
Treflan EC	pt	$ 4.02	2	$ 8.04	$ 4.02	2	$ 8.04
Surfactant	pt	$ 1.25	1	$ 1.25	$ 1.25	1	$ 1.25
2,4-D Amine	pt	$ 1.74	1	$ 1.74	$ 1.74	1	$ 1.74
Insecticide							
Vydate C-LV	oz	$ 1.39	8.5	$ 11.82	$ 1.39	8.5	$ 11.82
Guthion 2L	pt	$ 4.73	3	$ 14.19	$ 4.73	3	$ 14.19
Tracer	oz	$ 7.64	2	$ 15.28	$ 7.64	2	$ 15.28
Irrigation Supplies							
Drip Trailer System							$ 59.21
Drip Tape / Install							$ 91.93
Irrigation Water	ac-ft	$ 20.00	1.04166667	$ 20.83	$ 20.00	0.83333333	$ 16.67
Seed							
Cotton Seed	lb	$ 1.95	15	$ 29.25	$ 1.95	15	$ 29.25
Growth Regulator							
Pix	oz	$ 0.11	12	$ 1.32	$ 0.11	12	$ 1.32
Service Fee							
Insect Scouting	acre	$ 7.00	1	$ 7.00	$ 7.00	1	$ 7.00
Custom Harvest/Haul							
Haul Cotton	lb	$ 0.14	825	$ 115.50	$ 0.14	990	$ 138.60
Operator Labor							
Tractors	hour	$ 7.50	1.124	$ 8.43	$ 7.50	1.124	$ 8.43
Self Propelled Equipment	hour	$ 7.50	0.483	$ 3.62	$ 7.50	0.483	$ 3.62
Hand Labor							
Implements	hour	$ 7.50	0.331	$ 2.48	$ 7.50	0.331	$ 2.48
Irrigation Labor							
Labor (Flood)	hour	$ 7.50	1	$ 7.50	$ 7.50		
Labor (Irr. Setup)	hour	$ 7.50	0.1	$ 0.75	$ 7.50		
Labor (Drip)	hour	$ 7.50			$ 7.50	0.14	$ 1.05
Unallocated Labor	hour	$ 7.50	1.2856	$ 9.64	$ 7.50	1	$ 7.50
Diesel Fuel							
Drip Trailer System							$ 21.04
Tractors	gal	$ 3.10	8.53	$ 26.44	$ 3.10	8.53	$ 26.44
Self Propelled Equipment	gal	$ 3.10	1.926	$ 5.97	$ 3.10	1.926	$ 5.97
Repair and Maintenance							$ -
Implements	acre	$ 8.26	1	$ 8.26	$ 8.26	1	$ 8.26
Tractors	acre	$ 6.94	1	$ 6.94	$ 6.94	1	$ 6.94
Self Propelled Equipment	acre	$ 16.05	1	$ 16.05	$ 16.05	1	$ 16.05
Drip System	acre						$ 3.50
Interest on Operating Capital	acre	$ 16.33	1	$ 16.33	$ 16.33	1	$ 16.33
Total Direct Expenses				$ 580.98			$ 786.05
Returns Above Specified Expenses				$ 245.51			$ 196.77

Source: Texas AgriLife Extension Service (2012a) with own modifications

Exhibit A2. Crop Enterprise Budget for Furrow and Drip Irrigated Cotton, 2012

				Furrow			Drip	
	Item	Unit	Price	Quantity	Amount	Price	Quantity	Amount
Income	Sugar Cane	tons	$ 19.00	50	$ 950.00	$ 19.00	69.5	$ 1,320.50
Total Income					$ 950.00			$ 1,320.50
Direct Expenses								
	Fertilizer							
	Fert 10-34-0	cwt	$ 67.92	2	$ 135.84	$ 67.92	2	$ 135.84
	Herbicide							
	Atrazine 4L	pt	$ 2.15	12	$ 25.80	$ 2.15	12	$ 25.80
	Prowl 3.3 EC	pt	$ 4.35	10	$ 43.50	$ 4.35	10	$ 43.50
	Irrigation Supplies							
	Drip Trailer System							$ 59.21
	Drip Tape							$ 257.81
	Other Drip Materials							$ 82.85
	Irrigation Water	ac-ft	$ 20.00	5	$ 100.00	$ 20.00	4.12698413	$ 82.54
	Seed/Plants							
	Seed Cane	ton	$ 32.89	4.5	$ 148.01	$ 32.89	4.5	$ 148.01
	Custom Cane Operations							
	Seed Cutting	ton	$ 8.00	4.5	$ 36.00	$ 8.00	4.5	$ 36.00
	Seed Transport/distribution	acre	$ 160.00	1	$ 160.00	$ 160.00	1	$ 160.00
	Seed Covering	acre	$ 8.20	1	$ 8.20	$ 8.20	1	$ 8.20
	Operator Labor							
	Tractors	hour	$ 7.50	0.884	$ 6.63	$ 7.50	0.884	$ 6.63
	Hand Labor							
	Implements	hour	$ 7.50	0.101	$ 0.76	$ 7.50	0.101	$ 0.76
	Irrigation Labor							
	Labor (Flood)	hour	$ 7.50	6	$ 45.00	$ 7.50		
	Labor (Irr. Setup)	hour	$ 7.50	1	$ 7.50	$ 7.50		
	Labor (Drip)	hour	$ 7.50			$ 7.50	0.69333333	$ 5.20
	Unallocated Labor	hour	$ 7.50	0.7072	$ 5.30	$ 7.50	0.7072	$ 5.30
	Diesel Fuel							
	Drip Trailer System							$ 104.22
	Tractors	gal	$ 3.10	6.4875	$ 20.11	$ 3.10	6.4875	$ 20.11
	Repair and Maintenance							
	Implements	acre	$ 4.27	1	$ 4.27	$ 4.27	1	$ 4.27
	Tractors	acre	$ 5.74	1	$ 5.74	$ 5.74	1	$ 5.74
	Drip System	acre						$ 17.33
	Interest on Operating Capital	acre	$ 54.83	1	$ 54.83	$ 54.83	1	$ 54.83
Total Direct Expenses					$ 807.49			$ 1,264.16
Returns Above Specified Expenses					$ 142.51			$ 56.34

Source: Texas AgriLife Extension Service (2012a) with own modifications

Exhibit A3. Crop Enterprise Budget for Furrow and Drip Irrigated Sugarcane, 2012

	Item	Unit		Price	Flood Quantity	Flood Amount		Price	Drip Quantity	Drip Amount
Income	Grapefruit (rio red)	tons		$ 110.00	23	$ 2,530.00		$ 100.00	28.198	$ 3,101.78
Total Income						$ 2,530.00				$ 3,101.78
Direct Expenses										
	Fertilizer									
	Ammonium Sulfate (21% N)	cwt		$ 18.00	7.14	$ 128.52		$ 18.00	7.14	$ 128.52
	Herbicide									
	Simizine 90DF	gal		$ 20.47	5	$ 102.35		$ 20.47	5	$ 102.35
	Krovar I 80DF	lb		$ 19.10	3	$ 57.30		$ 19.10	3	$ 57.30
	Insecticide/miticide									
	Vydate	gal		$ 88.32	0.0625	$ 5.52		$ 88.32	0.0625	$ 5.52
	Vendex	lb		$ 35.30	6	$ 211.80		$ 35.30	6	$ 211.80
	Citrus Oil	gal		$ 3.36	5	$ 16.80		$ 3.36	5	$ 16.80
	Agri-Mek	gal		$ 873.60	0.054	$ 47.17		$ 873.60	0.054	$ 47.17
	Irrigation Supplies									
	Irrigation Water	ac-ft		$ 20.00	1.2	$ 24.00		$ 20.00	0.8868	$ 17.74
	Drip Trailer System									$ 59.21
	Drip Tape/Install									$ 93.19
	Adjuvant									
	Surfactant	pt		$ 1.33	2	$ 2.66		$ 1.33	2	$ 2.66
	Custom Orchard Spray									
	Lorsban 4E	pt		$ 6.28	8	$ 50.24		$ 6.28	8	$ 50.24
	Insurance									
	Established Grapefruit	acre		$ 115.00	1	$ 115.00		$ 115.00	1	$ 115.00
	Custom Orchard Ops.									
	Hedging or Topping	acre		$ 66.00	0.5	$ 33.00		$ 66.00	0.5	$ 33.00
	Custom Fert. Citrus	acre		$ 4.40	2	$ 8.80		$ 4.40	2	$ 8.80
	Custom Orchard Spray	acre		$ 38.50	4	$ 154.00		$ 38.50	4	$ 154.00
	Operator Labor									
	Tractors	hour		$ 7.50	0.122	$ 0.92		$ 7.50	0.122	$ 0.92
	Hand Labor									
	Implements	hour		$ 7.50	0.061	$ 0.46		$ 7.50	0.061	$ 0.46
	Irrigation Labor									
	Labor (Flood)	hour		$ 7.50	3	$ 22.50		$ 7.50		
	Labor (Drip)	hour		$ 7.50				$ 7.50	0.14898	$ 1.12
	Unallocated Labor	hour		$ 7.50	0.0122	$ 0.09		$ 7.50	0.0122	$ 0.09
	Diesel Fuel									
	Tractors	gal		$ 3.10	0.9419	$ 2.92		$ 3.10	0.9419	$ 2.92
	Drip System	gal								$ 22.39
	Repair and Maintenance									
	Implements	acre		$ 0.27	1	$ 0.27		$ 0.27	1	$ 0.27
	Tractors	acre		$ 0.64	1	$ 0.64		$ 0.64	1	$ 0.64
	Drip System	acre								$ 3.72
	Interest on Operating Capital	acre		$ 56.92	1	$ 56.92		$ 56.92	1	$ 56.92
Total Direct Expenses						$ 1,041.88				$ 1,192.75
Returns Above Specified Expenses						$ 1,488.12				$ 1,909.03

Source: Texas AgriLife Extension Service (2012a) with own modifications

Exhibit A4. Crop Enterprise Budget for Flood and Drip Irrigated Grapefruit, 2012

	Item	Unit		Price	Flood Quantity	Flood Amount		Price	Drip Quantity	Drip Amount
Income	Oranges	tons		$ 155.00	10	$ 1,550.00		$ 100.00	12.26	$ 1,900.30
Total Income						$ 1,550.00				$ 1,900.30
Direct Expenses										
	Fertilizer									
	Ammonium Sulfate (21% N)	cwt		$ 18.00	7.14	$ 128.52		$ 18.00	7.14	$ 128.52
	Herbicide									
	Simizine 90DF	gal		$ 20.47	5	$ 102.35		$ 20.47	5	$ 102.35
	Krovar I 80DF	lb		$ 19.10	3	$ 57.30		$ 19.10	3	$ 57.30
	Insecticide/miticide									
	Vydate	gal		$ 88.32	0.0625	$ 5.52		$ 88.32	0.0625	$ 5.52
	Vendex	lb		$ 35.30	6	$ 211.80		$ 35.30	6	$ 211.80
	Citrus Oil	gal		$ 3.36	5	$ 16.80		$ 3.36	5	$ 16.80
	Agri-Mek	gal		$ 873.60	0.054	$ 47.17		$ 873.60	0.054	$ 47.17
	Irrigation Supplies									
	Irrigation Water	ac-ft		$ 20.00	1.2	$ 24.00		$ 20.00	0.8868	$ 17.74
	Drip Trailer System									$ 59.21
	Drip Tape/Install									$ 93.19
	Adjuvant									
	Surfactant	pt		$ 1.33	2	$ 2.66		$ 1.33	2	$ 2.66
	Custom Orchard Spray									
	Lorsban 4E	pt		$ 6.28	8	$ 50.24		$ 6.28	8	$ 50.24
	Insurance									
	Established Grapefruit	acre		$ 85.00	1	$ 85.00		$ 85.00	1	$ 85.00
	Custom Orchard Ops.									
	Hedging or Topping	acre		$ 66.00	0.5	$ 33.00		$ 66.00	0.5	$ 33.00
	Custom Fert. Citrus	acre		$ 4.40	2	$ 8.80		$ 4.40	2	$ 8.80
	Custom Orchard Spray	acre		$ 38.50	4	$ 154.00		$ 38.50	4	$ 154.00
	Custom spot spray	appl		$ 24.00	1	$ 24.00		$ 24.00	1	$ 24.00
	Operator Labor									
	Tractors	hour		$ 7.50	0.122	$ 0.92		$ 7.50	0.122	$ 0.92
	Hand Labor									
	Implements	hour		$ 7.50	0.061	$ 0.46		$ 7.50	0.061	$ 0.46
	Irrigation Labor									
	Labor (Flood)	hour		$ 7.50	3	$ 22.50		$ 7.50		
	Labor (Drip)	hour		$ 7.50				$ 7.50	0.14898	$ 1.12
	Unallocated Labor	hour		$ 7.50	0.0122	$ 0.09		$ 7.50	0.0122	$ 0.09
	Diesel Fuel									
	Tractors	gal		$ 3.10	0.9419	$ 2.92		$ 3.10	0.9419	$ 2.92
	Drip System	gal								$ 22.39
	Repair and Maintenance									
	Implements	acre		$ 0.27	1	$ 0.27		$ 0.27	1	$ 0.27
	Tractors	acre		$ 0.64	1	$ 0.64		$ 0.64	1	$ 0.64
	Drip System	acre								$ 3.72
	Interest on Operating Capital	acre		$ 56.11	1	$ 56.11		$ 56.11	1	$ 56.11
Total Direct Expenses						$ 1,035.07				$ 1,185.94
Returns Above Specified Expenses						$ 514.93				$ 714.36

Source: Texas AgriLife Extension Service (2012a) with own modifications

Exhibit A5. Crop Enterprise Budget for Flood and Drip Irrigated Oranges, 2012

APPENDIX B

RESULTING CROPPING PATTERNS AS WATER DELIVERY COST WAS VARIED

Table B1. Cropping Patterns in Acres Across Varying Delivery Costs for 900,000 Acre-Feet of Water Available at Reservoir, 2012

	Water Delivery Cost per acre-foot			
Crop	$20	$60	$100	$500
Bell Pepper, Flood	3,377	3,131	2,811	0
Broccoli, Flood	10,814	6,309	3,017	0
Cabbage, Flood	29,996	29,999	30,178	21,885
Carrot, Sprinkler	2,500	2,500	2,500	2,500
Honeydew, Drip	2,304	2,383	2,351	2,135
Onion, Drip	1,467	1,438	1,384	883
Watermelon, Drip	1,061	1,377	621	0
Watermelon, Flood	21,635	21,240	22,028	4,086
Corn, Flood	16,465	9,529	942	0
Cotton, Drip	13,956	15,653	15,506	0
Cotton, Flood	129,609	120,396	112,787	60,123
Cotton, Dryland	6,435	13,951	21,706	89,878
Sorghum, Flood	241,547	253,259	255,707	110,747
Sorghum, Dryland	0	0	0	39,253
Sugarcane, Drip	8,671	6,717	11,353	10,012
Sugarcane, Flood	21,329	23,283	18,647	19,989
Orange, Drip	8,500	8,500	8,500	8,500
Grapefruit, Drip	18,500	18,500	18,500	18,500
Flood	474,772	467,146	446,117	216,830
Drip	54,459	54,568	58,215	40,030
Dryland	6,435	13,951	21,706	129,131

Table B2. Cropping Patterns in Acres Across Varying Delivery Costs for 650,000 Acre-Feet of Water Available at Reservoir, 2012

	Water Delivery Cost per acre-foot			
Crop	$20	$60	$100	$500
Bell Pepper, Flood	1635	1828	2005	0
Broccoli, Flood	5086	3548	1812	0
Cabbage, Flood	29287	29255	29135	21885
Carrot, Sprinkler	2500	2500	2500	2500
Honeydew, Drip	2478	2488	2490	2135
Onion, Drip	1445	1406	1366	883
Watermelon, Drip	2329	2284	2035	0
Watermelon, Flood	20193	20228	20475	4086
Corn, Flood	0	0	0	0
Cotton, Drip	11280	12234	12642	0
Cotton, Flood	98882	98097	96970	60123
Cotton, Dryland	39837	39669	40389	89878
Sorghum, Flood	202389	203804	205523	110747
Sorghum, Dryland	0	0	0	39253
Sugarcane, Drip	9417	9545	9702	10012
Sugarcane, Flood	20583	20455	20298	19989
Orange, Drip	8500	8500	8500	8500
Grapefruit, Drip	18500	18500	18500	18500
Flood	378055	377215	376218	216830
Drip	53949	54957	55235	40030
Dryland	39837	39669	40389	129131